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UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1298

Washington, D. C. ▼ April, 1925

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CONTROL OF DECAY IN PULP AND PULP WOOD

By

OTTO KRESS, formerly in charge, Section of Pulp and Paper, Forest Products Laboratory; C. J. HUMPHREY, Pathologist, and C. A. RICHARDS, Assistant Pathologist, Office of Investigations in Forest Pathology; M. W. BRAY, Chemist in Forest Products, and J. A. STAIDL, Assistant Engineer in Forest Products, Forest Products Laboratory, Forest Service, in cooperation with Bureau of Plant Industry

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1925

ACKNOWLEDGMENTS

Except for the cooperation of the pulp and paper manufacturers, who provided funds and generously assisted in furnishing mill data and material, this study would not have been possible. The writers are doubly indebted to the mills which made available their plant facilities for giving practical commercial tests to laboratory data which needed to be subjected to practical test before they could be indorsed fully.

The following companies cooperated in the study:

Beaver Board Co., Buffalo, N. Y.; Consolidated Water Power & Paper Co., Wisconsin Rapids, Wis.; Dells Paper & Pulp Co., Eau Claire, Wis.; Dexter Sulphite Pulp & Paper Co., Dexter, N. Y.; Dill & Collins, Philadelphia, Pa.; Eastern Manufacturing Co., Bangor, Me.; Falls Manufacturing Co., Oconto Falls, Wis.; Finch, Pruyn & Co., Glens Falls, N. Y.; Flambeau Paper Co., Park Falls, Wis.; Fort Orange Paper Co., Castleton, N. Y.; Grandfather Falls Co., Merrill, Wis.; Hammermill Paper Co., Erie, Pa.; Kimberly-Clark Co., Neenah, Wis.; Marathon Paper Mills Co., Rothschild, Wis.; Marinette & Menominee Paper Co., Marinette, Wis.; Minnesota & Ontario Paper Co., International Falls, Minn.; Nekoosa-Edwards Paper Co., Port Edwards, Wis.; Newton Falls Paper Co., Newton Falls, N. Y.; New York & Pennsylvania Co., Johnsonburg, Pa.; Northern Paper Mills, Green Bay, Wis.; Northwest Paper Co., Cloquet, Minn.; Patten Paper Co., Appleton, Wis.; Pejepscot Paper Co., New York, N. Y.; Port Huron Sulphite & Paper Co., Port Huron, Mich.; Racquette River Paper Co., Potsdam, N. Y.; Rhinelander Paper Co., Rhinelander, Wis.; Thilmany Pulp & Paper Co., Kaukauna, Wis.; Tidewater Paper Mills Co., Brooklyn, N. Y.; S. D. Warren Co., Boston, Mass.; Watab Paper Co., Sartell, Minn.; Wausau Paper Mills Co., Brokaw, Wis.; Wisconsin River Paper & Pulp Co., Neenah, Wis.; York Haven Paper Co., York Haven, Pa.

Acknowledgment is also made of the cooperation of the Newsprint Service Bureau, the American Paper and Pulp Association, the Canadian Pulp and Paper Association, and the Technical Association of the Pulp and Paper Industry, in the continuance of investigations to which there is occasional reference in this report.

The writers are especially indebted to John D. Rue, in charge of the section of pulp and paper, Forest Products Laboratory, for helpful comments and assistance.

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APPENDIX

IMPORTANCE OF DECAY PROBLEM IN PULP INDUSTRY

The pulping of wood for the production of paper and various fiber products is one of the major industries of the United States. It is largely concentrated in the northern region beginning with Minnesota and extending eastward. The six leading pulp-producing States

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are Maine, New York, Wisconsin, Pennsylvania, New Hampshire, and Minnesota. Thirty per cent of the newsprint-manufacturing industry is in New England, nearly 50 per cent in New York, and 15 per cent in the Lake States.

Statistics (*20*)[1] recently published will give some idea of the magnitude of the operations. During 1920, 253 establishments reported the use of 6,114,072 cords of wood valued at $116,495,720, with an average cost per cord of $19.05 f. o. b. mill. This material produced 3,821,704 tons of pulp, of which 1,583,914 tons were mechanical, 1,585,834 sulphite, 463,305 soda, and 188,651 sulphate pulp. The pulp wood consumption in 1920 showed an increase of 16 per cent over 1918. This demand was met in part by the importation of nearly a million and a quarter cords of spruce and poplar.

An abnormal demand for pulp developed in 1919, because of the world shortage following the war, and this continued until the latter part of October, 1920. Wood and pulp increased correspondingly in value, and losses from decay and mold, assuming greater monetary significance, came sharply to the attention of operators and evoked many requests for assistance in controlling or reducing the losses. The Federal Government did not have funds immediately available to finance the necessary investigative work, and a group of 33 interested mills subscribed to a fund which enabled the Forest Products Laboratory to employ two pathologists (who were detailed from the Bureau of Plant Industry) and two chemists to study the problem.

A preliminary survey of the situation was made at some twenty of the cooperating mills in Wisconsin, Minnesota, New York, and Pennsylvania. At these mills the problems were discussed with the operators, and inspections were made of wood and pulp storage facilities and methods. The survey disclosed heavy losses at most mills, particularly in the storage of wood, and past losses of considerable extent in the storage of ground wood pulp. One mill had lost more than $100,000 on ground wood stored inside for a comparatively short time. At another mill a loss exceeding $10,000 occurred in a 7,500-ton lot of hydraulic-pressed ground wood from Canadian spruce stored for two or three years. This was in an outside pile about 20 feet high, unprotected above but placed on a plank foundation. The company reported this pulp about 72 per cent air dry (65 per cent oven dry). There were also several instances in which ground wood, infected at one plant and shipped to another, had rotted very rapidly after arrival. Such direct cancellations of unsalable pulp from the books create a very distinct impression of loss; but there is a much greater loss, in the aggregate, from deterioration which is not sufficiently marked to cause rejection, though sufficient to reduce the market value of the product. All these elements the present investigators have tried to take into account.

Little attention has been paid in the past to losses from pulp wood rotting in the yard or in the woods. Rot has been recognized only after it became sufficiently advanced to affect the strength of the pulp, thus necessitating a larger proportion of sulphite to produce newsprint. In only one instance was wood found which was so far rotted as to be considered unfit for use. This had been in storage about four years. Many mills have been operating for years on

[1] Numbers in italics in parentheses refer to literature listed in "Bibliography," p. 80.

wood with a considerable admixture of decayed material, so that a "normal" yield with them is not the normal for sound wood, and losses figured on that basis would be underestimated. In fact, definite data on comparative losses in pulping sound and infected woods, either by mechanical or chemical processes, were lacking. Decay in the wood yard was considered rather an "act of Providence" than a direct result of storage conditions highly favorable to the growth of wood-destroying fungi.

Since the improvement of storage conditions in the wood yard and the working out of a method for the preservation of pulp by the addition of antiseptics appeared to be the two problems of greatest significance, it was decided to direct the investigative work especially along these lines.

The present study, however, combines investigations on all phases of the deterioration problem. Rarely is the opportunity offered, as in this case, to correlate mill tests and commercial practice with pathological and chemical laboratory investigations of the same material. It is the ideal way to conduct a commercial study.

The investigations cover the cause of decay in wood and wood pulp and the conditions which favor it. This information, when adapted to commercial practice, will go far toward reducing deterioration in these products.

The pulping characteristics of decayed wood have been investigated with special reference to the losses actually occurring under present commercial methods of storage. Pulping value depends to a large degree upon the nature of the process used. With decayed wood as raw material, mechanical pulp is characterized by low yields, dark color, and to some extent low strength; soda pulp by high consumption of chemicals, low yields, and decidedly low strength. Sulphite pulp, on the other hand, unless made from wood badly deteriorated, has characteristics not greatly different from those of pulp made from sound wood. The yield, when expressed in terms of weight of both wood and sulphite pulp, is not materially lower, although the pulp is slightly darker and becomes somewhat brittle when beaten. When the wood has become badly decayed, however, the deterioration is reflected more positively in the characteristics of the pulp.

In order to determine the relation between decay and pulping value, it was necessary to study the subject from both a chemical and a pathological angle. The investigations show that the changes in the wood substance leading to poor quality and quantity of pulp are due to a physical breaking down of the fibers accompanied by chemical changes in which even the cellulose is finally changed from a stable form to an unstable condition more soluble both in water and cooking liquor.

By the application of known principles of sanitation and rotation it is possible to reduce materially the losses which result from decay during the handling and storage of pulp wood. It is not feasible, however, to eliminate entirely from the mill all the pulp wood which has become decayed. The rapidity with which the pulp wood supply in the United States is vanishing makes it imperative that even the decayed wood be used wherever economically possible. Many trees are attacked by fungi and begin to rot while they are still on the stump, especially those which have reached maturity or those which have suffered from attack of insects, from suppression, or from mechanical injury. The extensive ravages of the budworm in the spruce and balsam forests, for example, have resulted in the death of more than 40 per cent of these important pulp-wood species in the areas affected. Trees weakened or killed by this pest quickly show signs of rot.

Investigations thus become necessary to determine to what extent deterioration can proceed before the wood loses its economic value for pulping. Such investigations are under way at the Forest Products Laboratory, and it is hoped that the results will lead to better methods of selecting the wood, to the end that the value of partially decayed material will be fully realized.

In connection with the control of decay and molding in pulp stored commercially, much attention has been devoted to the use of antiseptics introduced into the pulp to prevent the development of fungous growth. This was found necessary since no other remedy seemed at all feasible. During the progress of the investigation a brief report of the behavior of some of the most effective antiseptics and of the method of their application was distributed to the industry through the courtesy of the American Paper and Pulp Association.

As there are many fungi concerned in the deterioration of both pulp wood and stored pulp, it was necessary to determine which of these were the more detrimental. For this reason a large number of fungi were studied individually in pure culture in order to determine their action on wood fiber, and the resultant infected pulps were examined both chemically and physically with the same object in view. This investigation will be continued and expanded to include other fungi which produce rots of distinctive types prevalent in pulp-wood species.

DECAY OF WOOD

Decay in wood is produced by fungi. These fungi are plants, differing from the ordinary green plants merely in their form, lack of green coloring matter, and methods of nutrition. Ordinary plants get their nutriment from the soil and air; wood-destroying fungi utilize wood substance for this purpose.

Many fungi are wood inhabiting, but not all are wood destroying. In studying the effect of fungi on pulpwood and pulp it is necessary to discriminate between two broad groups of fungi—namely, molds and wood destroyers. Molds are abundant on pulp, particularly ground wood, but play so little part in the actual disintegration of wood fiber that their effect on its strength may be ignored. The active wood-destroying organisms are for the most part hymenomycetes, or fungi comparatively high in the scale of development. These fungi feed actively on the wood substance.

In the life cycle of wood-inhabiting fungi two essential stages of development are recognized: (1) The mycelial, or vegetative stage, during which the fine, cotton-like branched threads (the mycelium) of the fungus penetrate the wood and also develop on the surface if the surrounding air be moist; and (2) the fruiting stage, during which spores are produced for the further propagation of the fungus.

The mycelium (Pl. I, fig. 1) is the absorbing system of the fungus, and in function is comparable to the root system of ordinary green plants. In the case of molds, the mycelium enters chiefly the ducts or medullary rays of the wood, where it feeds on the starches, sugars,

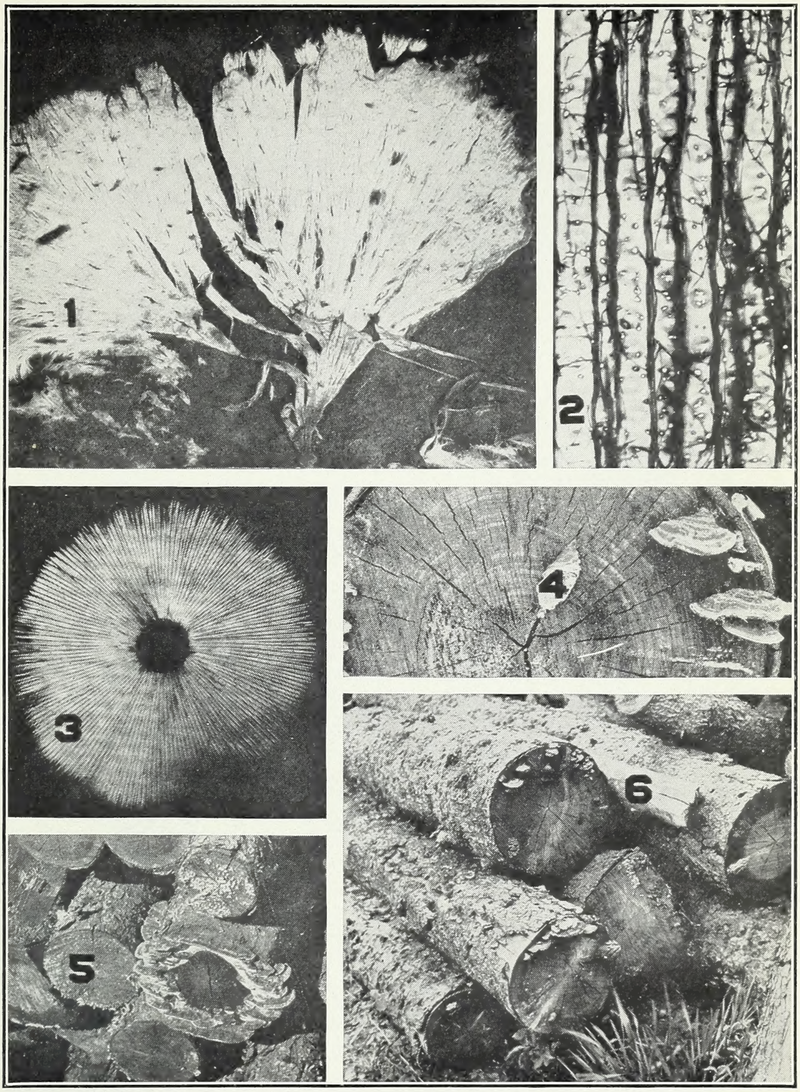

FIG. 1.—Mycelium of a wood-destroying fungus on ground wood after six months' storage in a mill basement

FIG. 2.—Mycelium of *Trametes pini* in southern yellow pine. The small black lines are the fungous threads. The heavy lines are the walls of the wood fibers. Note the numerous small holes where the threads have perforated the walls of the fibers

FIG. 3.—Spore print of a mushroom, *Lepiota naucina*, obtained by placing the cap, gills down, on a piece of black paper. The spores were cast by the billion. (After Atkinson)

FIG. 4.—Fruit bodies of *Polystictus hirsutus* on the end of an aspen pulp log. This fungus is limited to hardwoods

FIG. 5.—Fruit bodies of *Fomes roseus* (the larger) and *Polystictus abietinus* on the end of spruce pulp logs in the pile of three-year wood shown in Pl. VI, fig. 3. These two fungi are the most prevalent species on conifers

FIG. 6.—Fruit bodies of *Lenzites sepiaria* on spruce pulp logs. This fungus is confined almost entirely to conifers and develops readily on the drier exposed timbers

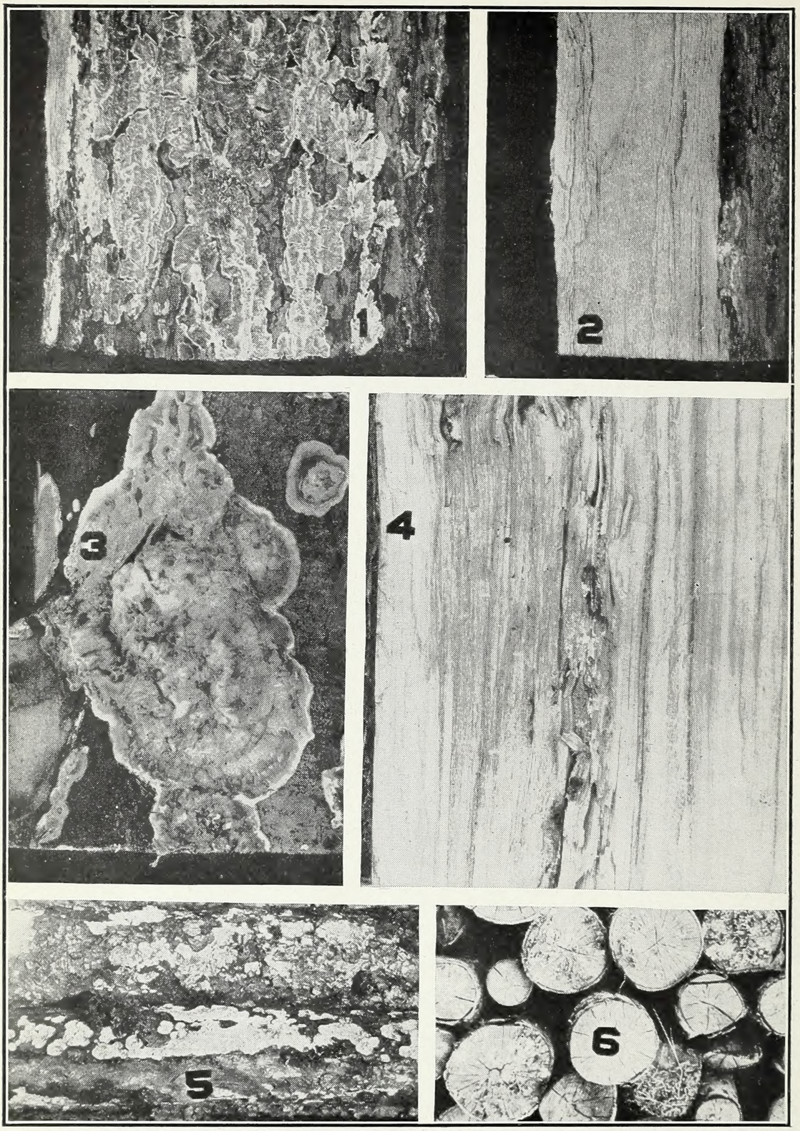

FIG. 1.—Encrusting fruit bodies of *Polystictus abietinus* on a hemlock pulp log. This fungus is very abundant on coniferous wood. The pore surface is violet when fresh

FIG. 2.—Longitudinal section of log shown in fig. 1. Note the minute pockets, primarily in the sapwood, which are characteristic marks of this fungus

FIG. 3.—Fruit bodies of *Polyporus adustus* on aspen pulp wood. The pore surface is smoky brown to smoky black. This fungus attacks hardwood pulp logs, particularly aspen, very vigorously.

FIG. 4.—Rot in log shown in fig. 3

FIG. 5.—Fruit bodies of *Stereum sanguinolentum* on spruce pulp log. At the ends of the log the fungus also forms small brackets. The spore-bearing surface "bleeds" if scratched when fresh. The fungus attacks mainly the sapwood of conifers and is not a severe wood destroyer

FIG. 6.—Fruit bodies of *Stereum purpureum* on aspen pulp logs. The spore-bearing surface is purplish when fresh. This fungus is particularly prevalent on aspen and apparently produces considerable decay. The wood shown had been in the yard less than a year

and other easily digested organic compounds. It may also pass through the pits in the walls of the wood fibers, but rarely bores through the solid wood substance. For this reason, molds on timber do not affect its pulping quality. The mycelium of wood destroyers, though often quite similar in appearance to that of molds, can usually be distinguished by its disintegrating action on the wood fiber. (See Pl. I, fig. 2.)

In order to propagate itself successfully, every fungus must have a fruiting or spore-bearing stage. The spores of molds are usually borne directly on somewhat specialized superficial mycelium. The spores of wood-destroying fungi are, with the exception of secondary ones produced in certain cases, borne on or within definite fruit bodies (conchs, brackets, toadstools, mushrooms, leathery incrustations, etc.), whose shape, color, and texture are quite characteristic for the different fungi. (See Pls. I, II, and XVIII.)

Spores, in function, are entirely comparable to seeds. They are microscopic in size and extremely light, and appear (Pl. I, fig. 3) as a very fine powder, which is very often white, though the color varies for different fungi. Frequently the spores from a single fruit body will number into the billions, most of them being capable of producing a new plant. With so many spores blowing about in the air and settling on new timber, it is evident that the chances for infection are very great, provided the conditions for germination are favorable. The most active period for the casting of spores from the fruit bodies is during moist weather, which in turn is most favorable for germination and subsequent infection.

CONDITIONS NECESSARY FOR GROWTH OF FUNGI

The conditions necessary for the growth of fungi are (1) the presence of an adequate food supply, (2) sufficient moisture, (3) at least a small amount of air, and (4) a suitable temperature.

Food is supplied by the wood tissues, and the more easily these tissues are attacked the more readily will the wood disintegrate. The sapwood of practically all species of American timber is nonresistant to fungous attack, and the heartwood of most of the principal pulp-wood species is hardly more durable than the sapwood.

Where there is a suitable food supply for the fungi, moisture is, without doubt, the most important factor in decay. The different fungi, however, appear to vary somewhat as to their water requirements. For infection and the early stages of decay a comparatively high moisture content of the wood and the surrounding air is highly favorable for all fungi. In discussing the effect of atmospheric moisture on the germination of spores of *Lenzites sepiaria* on shavings of shortleaf pine sapwood, Zeller (*28*) shows that 85 to 100 per cent of them germinate only at the high relative humidities of 98 to 99 per cent. This writer considers that fiber saturation [2] of the wood is attained at 95 to 96 per cent relative humidity, and concludes that even at this point germination is considerably retarded, and that below fiber saturation it falls off with extreme rapidity. A slight

[2] Green wood usually contains water within the cell walls and "free" water in the pores. In drying, the water in the pores is the first to be evaporated. The fiber saturation point is that point at which no water exists in the pores of the timber, but at which the cell walls are still saturated with moisture. The fiber saturation point varies with the species. The ordinary proportion of moisture, based on the dry weight of the wood, at the fiber saturation point is from 20 to 30 per cent.

film of water on the wood surfaces, he believes, is highly favorable to germination. Just what moisture content of wood is most favorable to decay after infection has once taken place is not known. Nor is it known what moisture is necessary for infection of sound wood from an infected stick lying in contact with it, so that the mycelium may grow from the one to the other. The study of this phase of the problem is complicated by the fact that moisture may possibly be added to the wood by direct secretion from the mycelium and by the breaking down of the wood substance itself, in which process water is one of the products formed. Decay may therefore appear in certain cases, to take place somewhat below fiber saturation.

A certain amount of air in the wood is absolutely necessary for the occurrence of decay. The fungi require it in their growth. When the wood is saturated, the air in the wood cells is displaced by water, and fungous growth and decay are impossible.

The fungi which decay pulpwood generally grow best at temperatures between 75 and 95° F. All will grow at much lower temperatures, but much more slowly. The most severe winter conditions do not kill them. They merely cease growing and remain dormant. On the other hand, a rise of temperature of but a few degrees above the optimum has a greater retarding influence on growth than a corresponding reduction. The conditions of moisture and temperature under which fungi thrive are such that in most pulp-wood regions they will find a favorable environment during the greater part of the year.

FUNGI THAT DECAY STORED PULP WOOD

The fungi which have been found causing extensive decay in stored pulp wood in the regions investigated are: *Polystictus hirsutus* (Pl. I, fig. 4); *Polystictus versicolor*, *Polyporus adustus* (Pl. II, figs. 3 and 4); *Stereum purpureum* (Pl. II, fig. 6); *Fomes roseus* (Pl. I, fig. 5); *Lenzites sepiaria* (Pl. I, fig. 6); *Polystictus abietinus* (Pl. II, figs. 1 and 2); *Stereum sanguinolentum* (Pl. II, fig. 5); and *Trametes pini*. The first four species mentioned attack hardwoods; the first three are particularly prevalent on aspen. The other fungi attack conifers. Other fungi found only occasionally are *Fomes pinicola*, *Lenzites trabea*, *Trametes heteromorpha*, *Tr. peckii*, *Pleurotus ostreatus*, *Schizophyllum commune*, *Corticium galactinum*, *Stereum rugosiusculum*, and *Hypoxylon cohaerens*. Many others are undoubtedly present, particularly in the southern and western regions. In Sweden (*15*) *Corticium evolvens* is reported as doing considerable damage to spruce. Those producing heart rot in living trees are *Fomes roseus*, *Fomes pinicola*, and *Trametes pini* in conifers, and *Pleurotus ostreatus* in hardwoods. *Trametes pini* produces the so-called "red heart," or "ring scale."

STORAGE OF PULP WOOD

CHARACTER OF WOOD AVAILABLE FOR PULPING

The principal woods used for pulping are: Spruce, 57 per cent; hemlock, 14.5 per cent; aspen, 6 per cent; balsam fir, 5.4 per cent; and various yellow pines, 5.3 per cent. Other woods used in smaller quantities are jack pine, white pine, white fir, tamarack, basswood, beech, birch, cottonwood, gum, maple, and yellow poplar.

On the whole, the species used are not resistant to decay, for which reason storage of them is difficult. The fact that a certain proportion of the wood reaching the mills is already infected or decayed in varying degrees (see Pl. III, fig. 1) makes the storage of this material even more difficult than that of the sound, since the fungi present at the time of piling will continue to develop rapidly under conditions favorable to their growth.

LENGTH OF STORAGE PERIOD

Most mills aim to carry only a year's supply of wood in the yard, but circumstances often render longer storage necessary. Wood from 2 to 4 years old was found at several mills and it required no specialist to see that such long periods of storage were disastrous under the conditions of piling that obtained. Pulping and chemical tests showed how the wood had deteriorated. Much of the storage loss is preventable by the introduction of better methods of piling and improved sanitation.

Pulp wood supplies, especially east of the Mississippi River, each year come from increasingly great distances from the mills. In some cases they are transported 1,000 miles or more. Much of the supply is at present coming from less accessible, often swampy, regions, where cutting operations are largely dependent on the condition of the terrain—winter being the favorable season for operations. This leads to a seasonal concentration in production and a corresponding congestion at points of delivery, instead of a regular and dependable supply. The growing scarcity of material is also a factor which induces many operators to stock heavily in order to insure adequate material.

The result is very often a heavy influx of timber into yards not equipped to handle it to the best advantage, because of limited space and insufficient labor. Demurrage charges must be kept down, and haste in unloading often leads to improper piling.

Changes can be brought about only by the close cooperation of the pulp-wood producer, the jobber, and the mill operator and his employees. These changes must be based on a thorough knowledge of the causes of decay and the conditions that favor it. It must be fully recognized that the improvements can be effected only if sufficient money is spent for the necessary facilities and labor, and for effective supervision of them.

HANDLING OF PULP WOOD AT WOODS POINTS

Care of pulp wood should start at production points. Observation shows that a large amount of infection and deterioration occurs before the wood reaches its destination.

TIME OF CUTTING

Winter is the best time to cut, since fungous and insect life is largely dormant at this season, and chances of infection are almost negligible. Infection by fungi occurs during warm, moist weather—particularly in the northern regions, in the summer and fall. In the South it may occur at almost any time of the year, but it is especially likely to take place during the rainy season. Since infection occurs mainly from spores, the most active infection period must coincide with the time of most active production of fruit bodies. In the more northern regions this occurs during the rainy fall months. In low, dense woods it may also occur during the summer. Fruit-body production in the spring months is not so abundant, but at the same time these months are usually so wet that timber can not be seasoned before the active infection period sets in.

REMOVAL OF BARK

Wherever feasible, removal of the bark from pulp wood at production points is strongly recommended. This greatly hastens the seasoning and also prevents insect attack. The bark of hemlock is sometimes removed for use in tanning. This should be encouraged.

METHOD OF PILING

Timber should never be left lying directly on the ground, for woods soil harbors a great variety of fungi, including many wood destroyers. It should be placed on log skids, with the piles separated and preferably built lengthwise to the prevailing winds. An open place on a well-drained slope should be selected wherever possible. Free circulation of the air is the prime consideration. As timber in the woods is much more subject to infection from slash and other rotting débris usually left by the logger, and as even under the best storage conditions available in the woods it can be better handled at the mill, it should be shipped as soon as possible.

STORING OF PULP WOOD AT THE MILL

REMOVAL OF BARK

If bark is not removed in the woods it is desirable, wherever feasible, that it be taken off at the mill before piling. Barked wood dries more rapidly and is less susceptible to insect and fungous attack than wood with the bark on. There is a market for hemlock bark, and its sale may offset the cost of removal.

SEPARATION OF WOOD

Separation of highly perishable species, such as poplar, balsam, and white fir, from the more durable woods may be considered desirable by some operators. In deciding this point, however, it should be kept clearly in mind that improved storage conditions will go far toward eliminating deterioration in mixed piles. The cost of separation will necessarily be considerable, and this item must, of course, be warranted by the returns.

Separation of badly infected shipments (Pl. III, fig. 3) from sound wood is strongly recommended. Although it is not economically feasible to pick out all rotten sticks from shipments of otherwise sound material, something can be done at times in this direction by a diligent yard crew. Badly infected shipments should always be segregated in an allotted portion of the yard for quick utilization. *This precaution is important. Deterioration in such wood is proportionately much greater than in sound or slightly infected stock. If it is intermixed with sound wood it serves as a rapid and vigorous source of infection to the better material.*

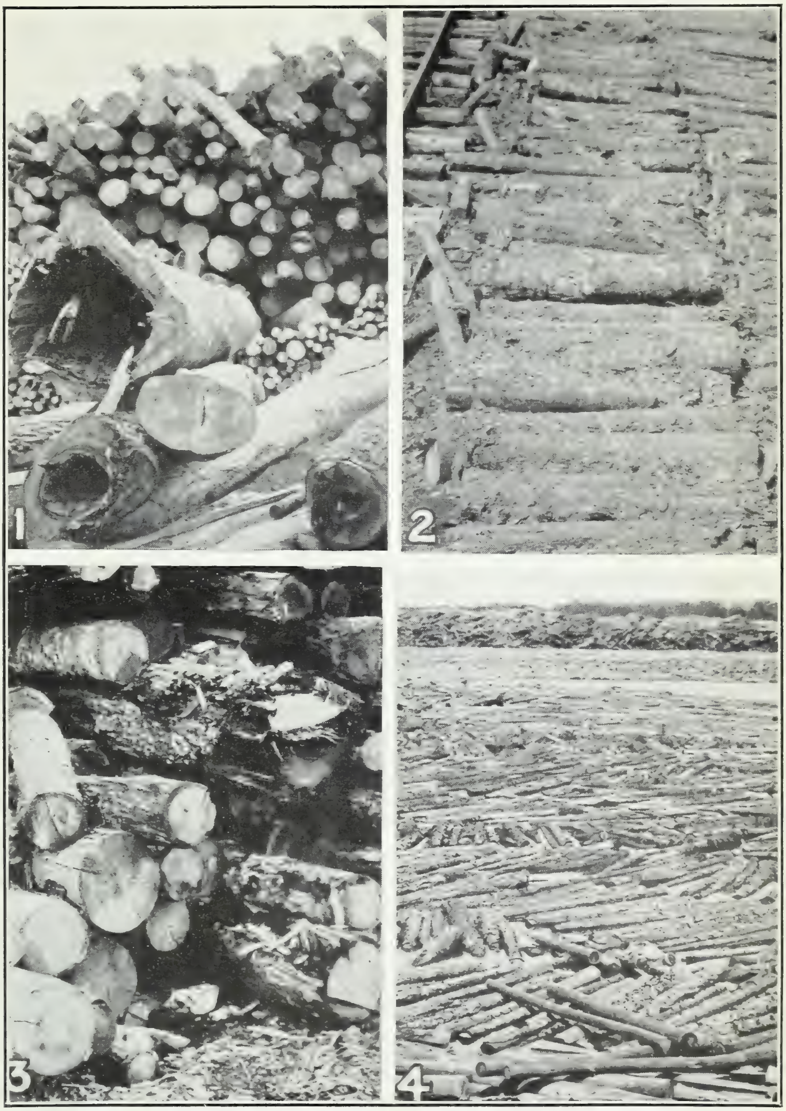

FIG. 1.—Heart-rotted hemlock as delivered to a mill. The largest log is about 3 feet in diameter with a shell of sound wood not exceeding 6 inches in thickness. A large proportion of hemlock is defective from heart rot

FIG. 2.—Bark and insect borings near the base of close-ranked piles of mixed spruce and balsam. Such débris hinders the seasoning process

FIG. 3.—Mixed spruce and tamarack pulp logs seen after they were received at a mill. Note the excessive amount of sap rot. These logs may have been rotten fallen material salvaged from the woods, or the decay may have developed during too long storage previous to delivery. Such wood should never be mixed with sound wood during storage

FIG. 4.—Eight-foot spruce stored in the river. Logs which are not kept saturated will decay

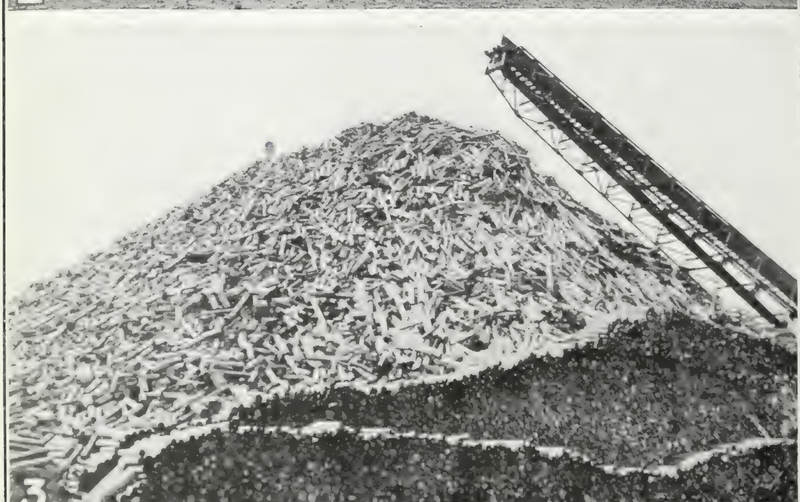

FIG. 1.—Spruce pulp wood unloaded indiscriminately into river, offering very favorable conditions for decay
FIG. 2.—Partial view of conveyor in use for 2-foot wood
FIG. 3.—Pile of 2-foot rossed spruce about 40 feet high and containing about 10,000 cords. The ricked wood in the foreground was so placed for the purpose of establishing a fire lane

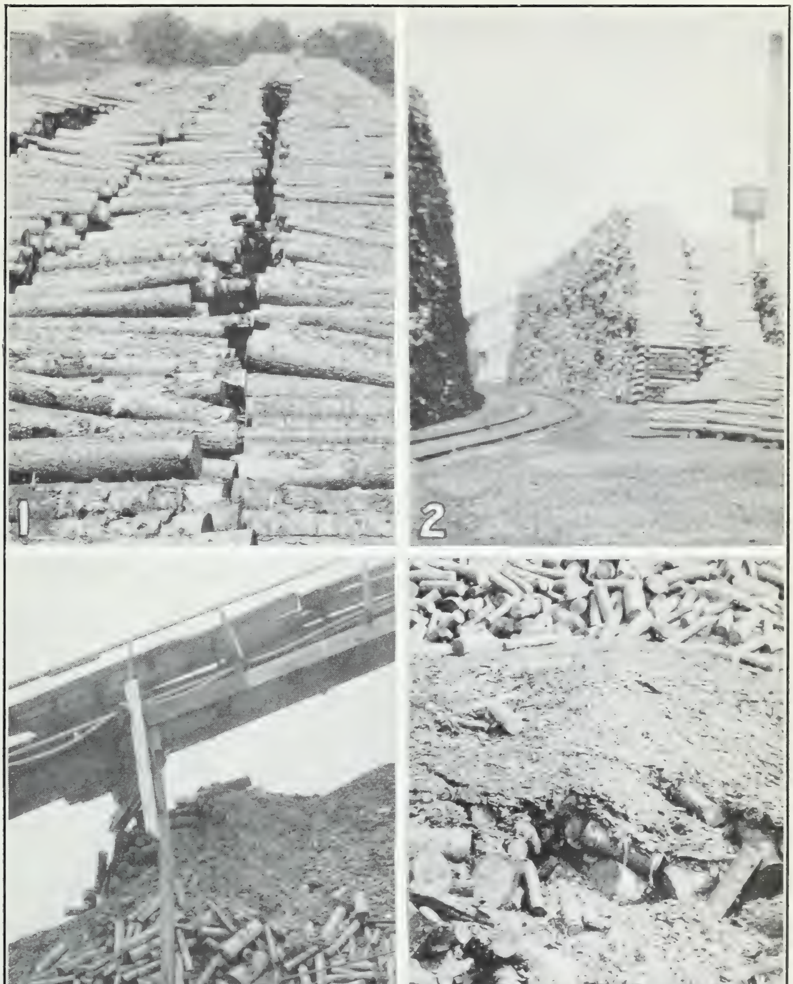

FIG. 1.—Ranked piles of 8-foot spruce. This type of massed piling, without adequate ventilation at the sides and beneath the ranks, leads to serious decay in a comparatively short time

FIG. 2.—Piles 35 feet high of 8-foot jack pine and spruce. Note the orderly arrangement and clean yard, conditions which are all too rare in the pulp industry

FIG. 3.—Bark and fragments of rotten wood which have been shaken down from the conveyor. Such detritus readily absorbs and holds moisture from rains and, in the case of any but water-soaked wood, promotes decay.

FIG. 4.—Bark and rotten wood at the base of a pile of 2-foot spruce and balsam stored for about one and one-half years. New rossed wood has been piled on this old, thoroughly infected base. Considerable loss from decay in the new wood may be expected from this source. Before starting new piles the old wood should be utilized and the surface of the ground cleared of all infecting material

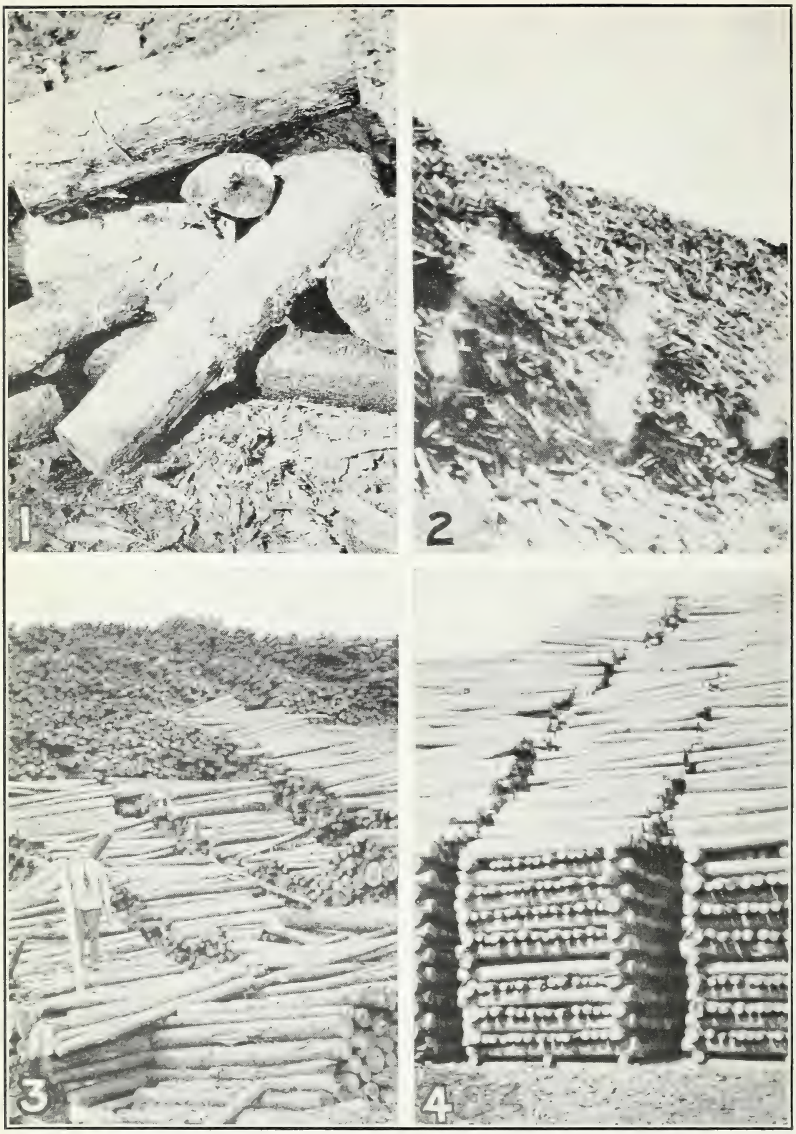

FIG. 1.—Representative samples of infected spruce and balsam taken from the base of the pile shown in Pl. V, fig. 4. These are badly decayed and will be almost worthless when utilized

FIG. 2.—Pile of pulp wood equipped with spray nozzles spaced 30 feet apart each way and delivering 2 quarts of water per minute. The nozzles should be higher, about 5 to 10 feet above the wood, in order to cover the pile. For the most efficient results and the best distribution of moisture, spray heads should be selected which break the water into the finest possible spray. (After Hoxie)

FIG. 3.—Piles of 8-foot spruce and balsam up to 35 feet in height placed directly on the ground and closely massed. This wood was found very severely decayed after three years' storage

FIG. 4.—Ranked piles of 8-foot tamarack, about 35 feet high, separated by a space of about 2 feet at the base, which permits considerable air circulation. Higher foundations would be advantageous

METHODS OF STORAGE

At the mill pulp wood is stored in the open in three ways: (1) In the water (Pl. III, fig. 4 and Pl. IV, fig. 1); (2) in conical piles of 2-foot wood built by means of conveyors (Pl. IV, figs. 2 and 3); and (3) closely ricked in long piles (Pl. V, figs. 1 and 2) up to 30 or 35 feet high.

Complete immersion in water is theoretically ideal storage, because wood in a saturated condition can not rot. In present commercial practice, however, complete immersion is not practicable. Most of the logs float, and often the exposed portion dries out sufficiently for decay to take place. Some logs are left on the river banks at low water; others, as they are unloaded from cars into the river, are left in a high pile extending out into the water. Under such conditions of exposure, wood is very liable to decay, particularly in a zone just above the water line.

In view of the difficulty of keeping the wood saturated, it is believed that storing the logs on well-drained land is preferable to holding them in the river, provided they are properly piled.

Of the two methods of piling pulp wood, ricking seems preferable to piling in large conical piles, provided the ricked piles are off the ground and, especially in the case of the smaller woods and shorter lengths, separated laterally one from another so as to allow continuous circulation of air. With hemlock, however, when stored green with the bark on, piling in close ricks may result in less decay than when the ranks are separated. The conical pile offers the advantage of requiring less space and trackage, but it has drawbacks from a pathological standpoint which, in many cases, can not be eliminated. Its volume is so great that drying takes place only in the outer part, and deterioration is apt to be rapid within. Drying is further retarded by the infiltration of bark débris, which rattles down from the conveyor (Pl. V, fig. 3) or is broken loose from rough wood in dropping. This débris is usually allowed to accumulate (Pl. V, fig. 4), and in time forms an excellent bed in which fungi (Pl. VI, fig. 1) can readily develop. Conical piles are placed directly on the ground, which is usually moist and thoroughly permeated with wood-destroying fungi, with the result that direct infection from the soil occurs. Because drying moist wood in large piles such as these is out of the question, the only alternative is to apply water in the form of a fine spray in an effort to keep the wood *too wet* for decay. Such a procedure, however, can be recommended only when the wood has a high water content at the time of piling.

Hoxie (*10, 11, 12*) has discussed the relation of moisture to decay and has advocated the use of the spray method (Pl. VI, fig. 2) both as a preventive of decay and as a precaution against fire. As regards moisture in the wood as stored, his observations are:

> The character of pulp wood with respect to moisture content varies widely at different mills. Wood which is river driven and is piled out wet after remaining in water for several months contains about 55 per cent moisture, and tests made on chips from this wood after remaining in the pile for one season indicate an average moisture content of from 45 to 50 per cent, which, from best information obtainable, is never below 40 per cent. On the other hand, wood delivered by rail at some mills shows a moisture content as low as 23 per cent.

In the present investigation, moisture determinations were made on a large number of wood samples, both sound and infected, which had been stored in ranked piles. No data were obtained on fresh river wood; but wet spruce and balsam, after storage in close-ranked piles at one mill for about a year, showed a maximum of 44.4 per cent and an average of 38 per cent. In one instance rotten 3-year-old samples taken from near the bottom of a large storage pile of solidly massed ranks of rail-shipped spruce showed a moisture content of from 33 to 35 per cent, which is practically the same as for green spruce. The top of a similar 35-foot pile ran about 27 per cent. Rotten spruce from another mill, probably stored for about the same length of time but in a much lower pile, was reduced to about 18 per cent. Green wood just off the cars contained about 40 per cent moisture.

The fact that spruce and balsam will rot rapidly in an essentially green condition argues against their storage in large conical piles, unless continuously water-soaked. Hoxie believes that wood with less than 40 per cent moisture is best stored in ranked piles. Snell (*25*) concludes from experiments with five fungi on spruce that decay is greatest at a moisture content of between 30 and 57 per cent, but that 60 per cent of water will eliminate all danger of serious loss from decay.

Present knowledge of the actual amounts of moisture which will preserve timber is based on observation, or unscientific experimentation. More careful investigations will undoubtedly reveal differences in the reactions of the various wood-rotting organisms toward water. Actual mill tests are highly desirable. It is well established that spruce and balsam containing 35 per cent moisture will decay readily. The few other records available indicate that in certain species considerable decay may also occur up to 80 or 90 per cent moisture content. Above this point the rate of decay may be much reduced.

Wood which reaches the mill in a partially dried condition is probably best stored in ranked piles so that drying may progress to a point where decay is markedly retarded or entirely inhibited. Precautions must be taken to get ample ventilation around and beneath the piles. Under present practices the ranks are often solidly massed without any possibility of air seasoning. (See Pl. VI, fig. 3.) Such a condition should be corrected by separating the ranks by a space of from 4 to 6 feet (Pl. VI, fig. 4) and running them in the direction of the prevailing winds. If they can be placed on a hillside in the direction of the slope, so much the better, as this will allow improved air drainage. Cross ventilation, accomplished largely by free air circulation through the foundations, should be provided for, as this assists in the removal of the humid air near the ground level and hastens seasoning in the bottom of the piles.

Ranked piles are sometimes placed directly on the ground (Pl. VII, fig. 1). In one case they were even piled in a drainage canal (Pl. VII, fig. 2). More often they are placed on parallel rows of poles or logs. The skid logs are commonly taken from the pulp-wood shipments as needed and kept in use as long as they are serviceable, frequently until they are in advanced stages of decay. On moist land they are often forced into the ground so far that sufficient air can not circulate underneath the piles. (See Pl. VII, fig. 3.) Inasmuch as rotten foundations will transmit infection to the wood piled on them, if pulp logs are to be used for foundations it is much better to use fresh logs for each new pile, removing the old ones and utilizing them for pulp, if suitable. Before new piles are started it is also good practice to rake up and remove all bark débris which has accumulated from the old ones.

A better type of foundation can be made by supporting creosoted stringers on concrete piers or creosoted wood blocks, with the footings sufficiently large to prevent them from being forced into the ground. The supports should be at least 12 inches high to allow ample side ventilation. A concrete foundation experimented with at one of the Wisconsin mills is similar to a rail in section and 10 feet long. The base is 18 inches broad, and the web is provided with 5-inch circular openings spaced 12 inches apart. (See fig. 1.) This has been found of sufficient strength to stand up under the hardest usage it is likely to get with large 12 to 16 foot hemlock logs. (See Pl. VII, fig. 4.)

ROTATION OF WOOD

None of the wood should be held in storage longer than absolutely necessary, for losses during the second and third years are entirely out of proportion to those of the first year. No method of storage which

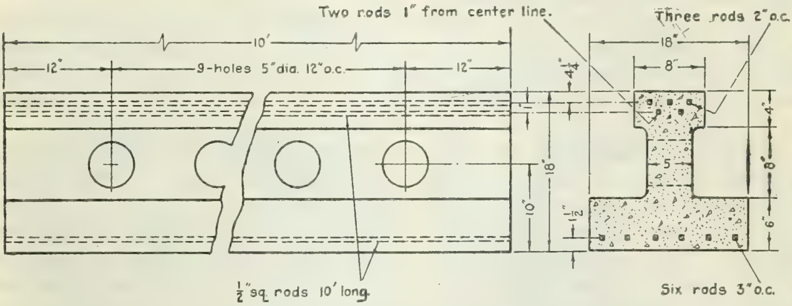

FIG. 1.—Sketch and specifications for precast reinforced-concrete skid in experimental use at a Wisconsin mill

is economically feasible will fully protect wood for long periods, and mills should make every effort to reduce the storage time to a minimum. The time in storage should be reckoned from the date of cutting and due allowance made accordingly in assigning a rotation number, which should be plainly marked on each pile (Pl. VIII, fig. 1) or section of a pile in the yard. The material should always be sent to the wood room in the order indicated. Large conical piles should be completely utilized. New wood should never be piled on old wood at the base. The same attention should be paid to cleaning up bark débris at the bottom of these piles as would be given to ranked piles.

In order that the wood may be piled most conveniently for later utilization, a survey of the yard is highly desirable. Following this, a diagram and blue prints can be prepared for the use of the yard crew, so that a definitely prearranged plan will be available to counteract a tendency toward indiscriminate piling.

GENERAL SANITATION

Many yards are littered with rotten or infected wood or bark débris which should be removed and burned. Infection of new wood may spread from this in two ways, namely, by spores from fruit bodies developing on it and by direct contact which permits the mycelium to grow from one stick to another. Bark débris (Pl. VIII, Fig. 2) and fragments of rotten wood on the ground form an excellent bed for the growth of fungi, since the mass is usually in a moist condition.

The wood which is in too bad condition for pulp should be burned, and noticeably infected wood which is still usable should be segregated and utilized as soon as possible and not mixed in piles with with sound material.

In order to insure better surface drainage (Pl. VIII, fig. 3) and greater cleanliness, it is advisable to surface yards with cinders (Pl. VIII, fig. 4) to a depth of 4 to 6 inches. Incidentally, this will keep down the grass and weeds which impede air circulation around the base of piles.

At most mills the cleaning-up program must be carried out gradually as opportunity permits. Where débris has been accumulating for a number of years the task will call for concerted and special effort. In some cases it may even prove advisable to change the location of the yard rather than attempt to put it in satisfactory condition. This would apply particularly to low yards where large amounts of filling are required

Every yard should be sufficiently drained to insure immediate run-off after rains. Earth is much better for filling than barker waste or other woody débris, which if not kept saturated with ground water will soon rot and furnish an uneven and unstable foundation for the piles. In any case the yard should be heavily cindered.

One Wisconsin mill employs a clean-up crew to look after the general sanitary condition of the yard. At least one or two men are continually at work digging out weeds and grass (Pl. VIII, fig. 4), raking up bark débris, etc. The wood yard at this mill is well drained and is surfaced with cinders, and there is no appreciable loss from decay during the storage period which is usually not longer than two years. This condition shows quite conclusively the advantages to be derived from a good location and attention to sanitary details.

Spraying the ground beneath piles with a "weak tannic acid solution" (*19*) or any other antiseptic, is not recommended. Tannic acid is not an effective fungicide, and treatment with an effective antiseptic is too expensive in proportion to the benefits derived.

SUMMARY OF RECOMMENDATIONS

It is believed that if the recommendations just given are consistently followed, losses in stored wood can be for the most part prevented. The big outstanding fact is that present conditions, wherever they favor fungous attack, must be corrected before mills can hope to eliminate deterioration from these causes. The extent of loss in the wood yard has never been fully realized. All other operations about the mill are closely scrutinized, and are corrected wherever losses are exposed. Why except the wood yard? It may require expert assistance to get the best results, but once the system gets under way it becomes largely a question of close attention to detail. Money will have to be spent, just as it must be spent in the replacement of old machines with more modern ones in order to meet close industrial competition. Taking as a very conservative estimate a shrinkage in value of $1 to $1.50 per cord for wood cut one and one-

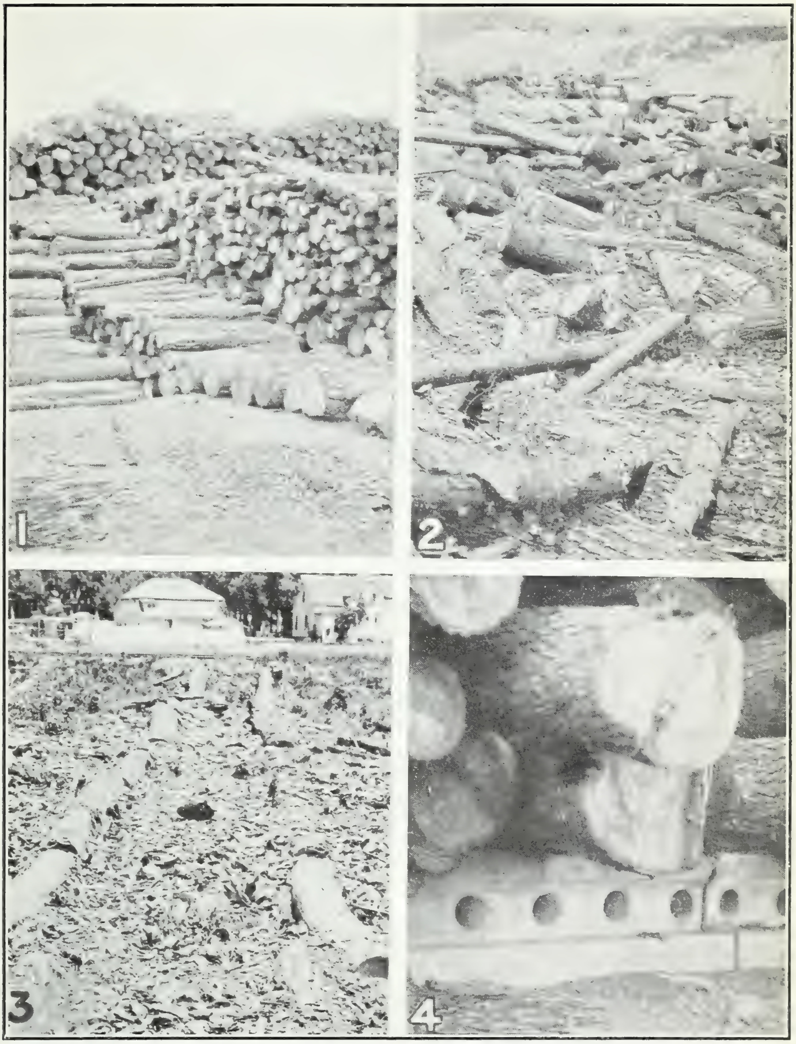

FIG. 1.—Four-foot hemlock piled directly on the ground and with no spacing between the ranks. Wood should never be placed directly on the ground. Even if these ranks had been separated, the pile in the background running at right angles to them would have cut off most of the air circulation

FIG. 2.—Hemlock pulp logs 12 to 14 feet long piled in a drainage canal 12 feet deep. The logs which are not wholly submerged will decay with extreme rapidity, owing to the moisture conditions being favorable to decay and the impossibility of further drying

FIG. 3.—Hemlock logs used as foundations for 12 to 14 foot pulp wood. The accumulation of bark from the handling and peeling of logs is nearly at the top of the rotten foundations, so that the wood might about as well be piled on the ground. The whole mass is an excellent fungus bed

FIG. 4.—Concrete skid, built according to the sketch shown in fig. 1 (p. 11), in experimental use at a mill

FIG. 1.—Pulp wood piles marked with date of arrival at the mill, to be used in rotation

FIG. 2.—Bark accumulation resulting from the hand peeling of hardwoods, a source of infection to wood piled on it. It was several feet thick over the entire yard

FIG. 3.—A storage yard on swampy ground. Pulp and pulp wood can not be stored under such conditions without heavy loss. Certain portions of the yard were being raised several feet with barker waste, surfaced with cinders. Earth and cinders would serve the purpose much better

FIG. 4.—Wood yard surfaced with cinders and located on a well-drained slope. The company recognizes the value of cleanliness and employs a crew to rake up and remove all accumulated bark and rotten wood. Workman "spudding" out grass and weeds and leveling the cinders. Wood is not usually stored longer than a year, and there is no appreciable loss from decay

half to two years, the losses for an average mill will be a very considerable item. As these can largely be prevented through the improvement of storage conditions, at least part of the money represented in losses might well be invested for their prevention.

The points to be emphasized in handling pulp wood are:

1. Timber should be left in the woods the shortest possible time, and while it is there it should be stored on skids, on a well-drained site fully exposed to the wind, in separate piles running, preferably, in the direction of the prevailing winds.

2. If borers are troublesome, soaking in water and peeling are effective.

3. Logs should, if possible, be peeled, in order to hasten air drying and also to prevent borers from attacking the wood.

4. Badly infected shipments or portions of shipments should be separated from sound wood and segregated for rapid utilization.

5. Wood should be stored at the mill on well-drained land. The site should have a cindered surface which will give rapid run-off and keep down weeds which hinder air circulation around the base of piles. Barker waste is a poor filling material, because it harbors fungi and forms a very unstable foundation for piles, even when surfaced with cinders.

6. Conical piling by the use of conveyors is not considered as good as ricking for partially dried wood. For river wood it seems satisfactory, when the piles are equipped with an overhead spray system to keep the surface moist. The method needs testing under commercial conditions, however, in order to determine more exactly the percentage of moisture in the wood necessary for protection. The sprays are also valuable features for fire prevention.

7. Wood should never be ricked directly on the ground. The best procedure is to use reinforced concrete skids provided with sufficient openings to insure good cross-ventilation or concrete piers supporting stringers which have been given a pressure treatment of coal-tar creosote. If treated properly, either of these types should last 20 to 25 years. The latter is preferred because it gives better cross-ventilation. If it is not considered feasible to equip the yard with concrete piers, the next best method would be to use wood blocking, pressure-treated with coal-tar creosote, as supports for the stringers. The stringers should, in any case, be at least 12 inches, preferably 18 inches, off the ground. If pulp logs are used they should be of the larger sizes and should be pulped or removed when the piles are torn down.

8. High-ranked piles should, as a rule, be separated by open spaces 4 to 6 feet wide and with their length in the direction of the prevailing winds. Between low piles a 3 to 4 foot space should be sufficient.

9. Each pile should be marked with the date on which it was piled, or if possible with the date of cutting. The piles should be used in the order they were cut.

10. All decayed and unserviceable wood should be removed from the yard, and after the removal of a pile of wood the bark should be cleaned up.

PULPING CHARACTERISTICS OF DECAYED WOOD

PHYSICAL PROPERTIES OF MECHANICAL PULP MADE FROM SOUND AND DECAYED SPRUCE

CHARACTER OF WOOD USED

In order to demonstrate the large losses sustained and the difficulties encountered in the use of decayed wood, comparative grinder runs were made on sound and on decayed spruce wood at one of the cooperating mills.

The sound wood, sample 1 (Pl. IX, fig. 1), was 12-foot Wisconsin spruce taken direct from a car which had just been received at the mill.

The decayed wood, sample 2546 (Pl. IX, fig. 2), represented ordinary mill-run Minnesota spruce, approximately 3 years old. It had been stored in 8-foot lengths directly on the ground, in close ricks, in a solid mass of several thousand cords. (See Pl. VI, fig. 3.) The logs used for the grinder runs were selected from the lower half of the piles. They were representative of severely infected material, but no wood was so badly decayed that it would have been rejected by the mill.

The principal fungi rotting the wood, in the order of their frequency, were *Fomes roseus*, *Stereum sanguinolentum*, *Polystictus abietinus*, *Lenzites sepiaria*, and *Trametes pini*. A tally of 184 of the 250 sticks showed 75 sticks infected with the first fungus, 59 with the second, 28 with the third, 16 with the fourth, and 6 with the fifth. *Fomes roseus* was represented in the living tree to a certain extent as a heart-rotting organism, but most of the rot probably developed in the pile. *Trametes pini* was undoubtedly introduced altogether as heart rot from the standing tree. All the other fungi developed from infections subsequent to cutting. Of these, *Lenzites sepiaria* readily attacks both heartwood and sapwood; *Stereum sanguinolentum* and *Polystictus abietinus* attack the sapwood principally.

METHOD OF PREPARATION

Approximately 5 cords each of infected and sound wood were selected, weighed, and ricked. This material was then sampled by cutting disks 6 inches thick for specific gravity determinations (Pl. IX, fig. 3) and thinner disks for moisture determinations. The moisture disks were weighed directly after cutting, wrapped in paper to prevent loss of small particles of bark and wood, and sent by express to the laboratory for the actual moisture determination. Fourteen of the sound and 26 of the infected sticks were sampled in this manner.

After being sampled the logs were dumped into the hot pond and cut into 2-foot bolts, all the odds and ends being collected and weighed and this weight deducted from the weight of the rough wood. The 2-foot bolts were barked on knife barkers and corded in cord ricks.

Preliminary to grinding, the ground-wood chest was run dry and washed out. Two 3-pocket grinders were used, with a pressure of 35 pounds per square inch on the piston heads and an average speed of 220 revolutions per minute. The stones were sharpened equally for both runs. The temperature of grinding varied between 120 and 180° F. (49 to 82° C.). After the separated screenings were weighed the pulp was run over the wet machine and the dry weight calculated. The essential data obtained from these tests are shown in Table 1.

TABLE 1.—*Data on the grinding of sound and decayed spruce*

	Sound wood, sample 1	Decayed wood, sample 2546
Quantity of wood ... pieces	[1] 140	[2] 250
Weight of rough wood ... pounds	17, 920	18, 839
Weight of rough wood, oven-dry [3] ... do	10, 720	12, 600
Loss in barking, based on oven-dry wood ... per cent	32. 4	31. 3
Weight of barked wood, oven-dry ... pounds	7, 250	8, 650
Yield of pulp, oven-dry weight ... do	6, 826	6, 783
Yield of oven-dry pulp, based on oven-dry barked wood ... per cent	94. 2	78. 4
Yield of oven-dry pulp, based on oven-dry rough wood ... do	63. 7	53. 8

[1] 12-foot lengths. [2] 8-foot lengths. [3] Computed from moisture samples.

YIELD AND QUALITY OF PULP

The results of this particular trial indicate a yield of 94.2 per cent in the case of the sound and of 78.4 per cent in the case of the decayed wood, on the basis of oven-dry weights in each case. Decay thus accounts for a loss of 15.8 per cent.

A sample of the pulp from each grinder run was shipped to the Forest Products Laboratory for physical and microscopic examination and for paper-making trials. Samples were also placed in moist storage for further observation, as described later.

Sedimentation tests indicated that the pulp made from decayed wood was slightly freer than that made from sound wood, although the difference was not marked. Microscopic examination of the average length of fiber particles showed 1.57 millimeters for the sound in comparison with 1.27 millimeters for the decayed material. The decayed pulp contained about twice as much débris, in the form of very small particles evidently produced by pulverizing the infected wood in the grinding. A large percentage of this débris would, of course, be lost during conversion on the paper machine, so that white water losses from decayed pulp should be larger than for sound pulp.

The stock was run into 100 per cent ground-wood sheets without the use of size, alum, or color. Physical tests on the papers, as shown in Table 2, indicate that both stocks, in so far as these runs would show, were of about the same strength. The pulp made from decayed wood, however, contained the larger number of shives and was decidedly the darker of the two in color.

TABLE 2.—*Data on waterleaf papers made from sound and from decayed spruce woods*

Sample No.	Description	Weight of ream, 24 by 36—500	Points per pound per ream	Average breaking length	Average stretch	Temperature	Humidity
		Pounds		*Meters*	*Per cent*	*° F.*	*Per cent*
1AA	From sound wood, No. 1	47	0. 304	2, 760	1. 4	87	64. 5
2AB	From decayed wood, No. 2546	48	. 304	2, 610	1. 3	85	64. 0

PHYSICAL PROPERTIES OF SULPHITE AND SODA PULPS MADE FROM SOUND AND FROM DECAYED WOOD

CHARACTER OF WOOD USED

Investigations were made at the Forest Products Laboratory to determine the effect of decay in wood on the yield and on the quality of chemical pulps made from it, and to ascertain the difficulties encountered in manufacturing paper from such pulps.

Through the courtesy of the cooperating mills, shipments of spruce, hemlock, and aspen woods representing sound wood and wood in various stages of decay were received. These woods may be described as follows:

Sample 2545. Spruce wood from a Wisconsin mill; nearly free from decay; taken from the top of a pile approximately 35 feet high, containing about 10,000 cords of 8-foot wood. Used for sulphite cook No. 7, pulp designated as No. 2547.

Sample 2546. Spruce wood; considerably decayed; taken from the bottom of the same pile from which No. 2545 was taken. Used for sulphite cook No. 6, pulp designated as No. 2548.

Sample 2560. Spruce wood from a Wisconsin mill; nearly free from decay and in physical appearance similar to No. 2545. Used for sulphite cooks Nos. 8 and 10, pulp designated 560A and 560, respectively, and for soda cook No. 6, pulp designated as No. 2559.

Sample 2541. Spruce wood from a Wisconsin mill; so badly decayed that it was rejected at the pulp mill. (See Pl. IX, fig. 4.) Used for sulphite cook No. 9, pulp designated as No. 2555, and for soda cook No. 7, pulp designated as No. 2557.

Spruce wood, not numbered; presumably sound; received at the Forest Products Laboratory and cooked prior to these studies. Used for sulphite cook No. 336, pulp designated as No. 2540.

Spruce wood, not numbered; presumably sound; received at the Forest Products Laboratory prior to these studies. Used for soda cook No. 109, pulp designated as No. 540.

Sample 2552. Aspen wood selected at random from a Michigan mill pile; extent of decay not certain. Used for sulphite cook No. 1, pulp designated No. 5521, and for soda cook No. 4, pulp designated as No. 552D.

Aspen wood, not numbered; presumably sound; received at the Forest Products Laboratory and cooked prior to these studies. Used for sulphite cook No. 351, pulp designated as No. 50.

Sample 2542. Hemlock wood from a Wisconsin mill; considerably decayed; used for sulphite cooks Nos. 2, 3, and 5, pulps designated respectively 542A, 542B, and 542C, and for soda cook No. 3, pulp designated as 542D.

Sample 2554. Hemlock wood from the same mill from which No. 2542 was received; sound; used for sulphite cook No. 4, pulp designated as No. 554.

Hemlock wood, not numbered; presumably sound; received at the Forest Products Laboratory and cooked prior to these studies. Used for soda cook No. 228, pulp designated as No. 40.

CHIPPING LOSSES

On account of the breaking down of the fibers by the fungi, decayed wood is brash. In the chipping of such wood a considerable loss occurs in "sawdust" and shives which are rejected by the screens. Trial chipping and screening of sound and decayed spruce wood from the lot under investigation gave the following screening losses in per cent by weight:

	Per cent loss
Sound	4. 4
Relatively sound (No. 2545)	5. 6
Somewhat decayed (No. 2560)	13. 2
Considerably decayed (No. 2546)	15. 6
Badly decayed (No. 2541)	17. 0

FIG. 1.—Fresh sound spruce used for experimental grinding in comparison with the infected wood shown in fig. 2

FIG. 2.—Rick of infected spruce wood used for experimental grinding. This was representative of the material toward the base of the pile shown in Pl. VI, fig. 3

FIG. 3.—Specific gravity disks cut from the infected spruce shown in fig. 2. Sample 23 was decayed by *Lenzites sepiaria* and *Polystictus abietinus*, sample 21 by *Stereum sanguinolentum*, and sample 19 by a fungus which was not fruiting and hence indeterminable

FIG. 4.—Spruce wood about four years old sent to the laboratory for sulphite and soda cooking tests. This wood was rotted mainly by *Fomes roseus* and was too far gone for commercial use

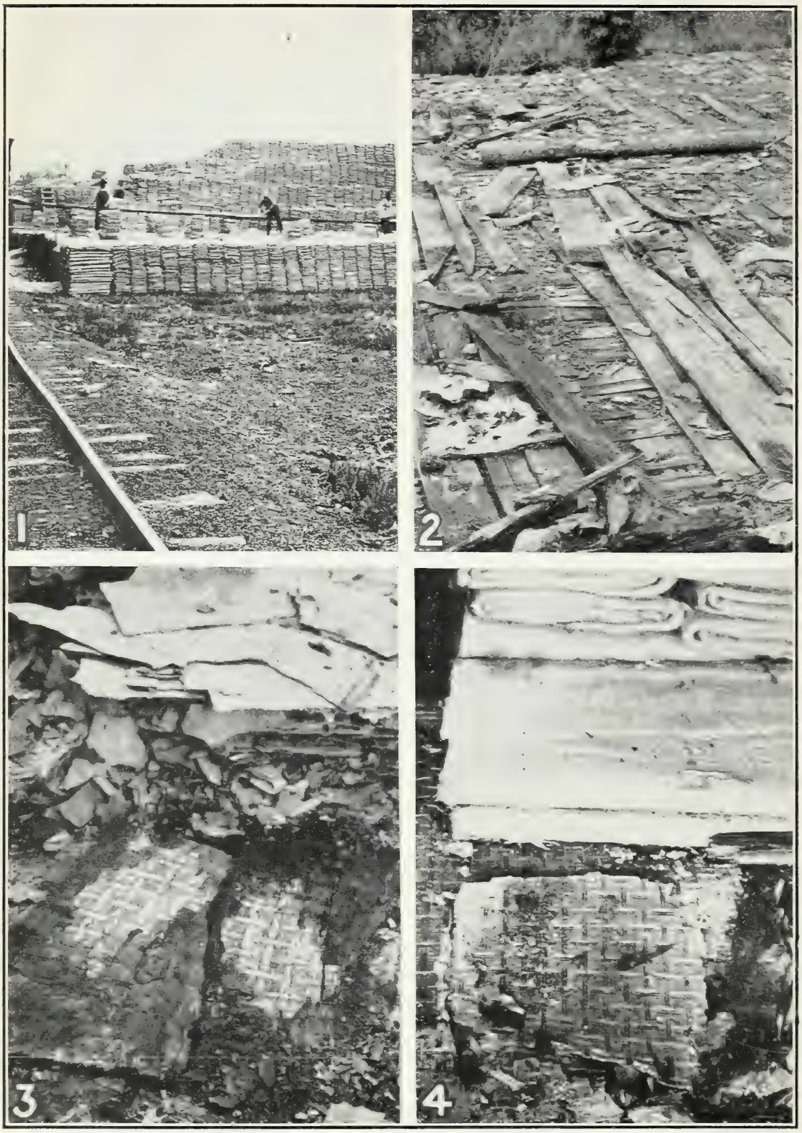

FIG. 1.—New ground-wood pulp placed directly on ground. A concrete base would prevent all infection from the ground upward into the base of the pile

FIG. 2.—Rotten platform recently used for ground wood. It rests directly upon moist soil, from which it became infected. If plank foundations are to be used, all decaying material should first be removed from the site, the ground surfaced with cinders, and fresh new timber used for each pile. In the long run a concrete base will be found much better and cheaper

FIG. 3.—Base of a pile of hydraulic-pressed ground-wood pulp stored two years in an open shed. The light area to the right is a very rotten spot in the floor, from which the piece of pulp to the left has been turned back. The indication is clear that this particular decayed area in the pulp originated from the floor

FIG. 4.—New ground-wood pulp stored on a rotten base consisting of hydraulic-pressed ground-wood pulp two years old. The floor is also completely decayed. Under no circumstances should clean pulp be placed in contact with decayed or infected material

Even though the equipment used in this instance is not comparable with mill equipment, the results show the relative effect of decay upon this type of loss.

PREPARATION OF SULPHITE PULP

Both sound and decayed spruce, hemlock, and aspen were cooked by the sulphite process in the laboratory digester, under conditions as nearly uniform as possible. In Table 3 are indicated the conditions of cooking and the respective yields. The data on cooks Nos. 351 and 336, of sound aspen and sound spruce, respectively, were taken from the laboratory records of previous tests and were used for purposes of comparison.

TABLE 3.—*Sulphite cooks of sound and decayed woods*

[Yield percentages are based on oven-dry weights of wood and pulp]

Sample No.	Cook No.	Pulp No.	Description	Time of cook	Max. temp.	Total SO_2	Free SO_2	Combined SO_2	Yield of crude pulp	Yield of screenings	Yield of screened pulp	Bleach (35 p.ct. available chlorine)
				Hours	° C.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
--------	336	2540	Spruce, sound	8.25	153	5.86	4.56	1.30	47.1	0.4	46.7	14
2545	7	2547	Spruce, decayed	8	152	5.34	4.10	1.24	44.6	.8	43.8	14
2560	8	560A	do	8	155	5.50	4.37	1.13	47.4	.6	46.8	16
2560	10	560	do	8	153	5.50	4.35	1.15	45.9	.8	45.1	16
2546	6	2548	do	8	152	5.45	4.28	1.17	43.9	.4	43.5	14
2541	9	2555	do	8	153	5.56	4.45	1.11	39.6	1.2	38.4	20
2554	4	554	Hemlock, sound	8	153	5.38	4.36	1.02	46.6	.5	46.1	36
2542	2	542A	Hemlock, decayed	8	152	5.44	4.33	1.11	44.9	.7	44.2	26
2542	3	542B	do	8	153	4.92	3.83	1.09	46.6	.8	45.8	35
2542	5	542C	do	8	153	5.36	4.27	1.09	46.8	.7	46.1	44
--------	351	50	Aspen, sound	8.25	152	5.50	4.20	1.30	47.5	.1	47.4	12
2552	1	5521	Aspen, decayed	7	153	4.28	3.14	1.14	42.1	.0	42.1	19

PREPARATION OF SODA PULP

Soda cooks were made only on decayed specimens of the three woods. The cooking conditions were maintained as nearly uniform as possible except in the case of the aspen, for which a larger amount of chemical was used. In Table 4 are given the cooking data. The data shown for cooks Nos. 109 and 228, on sound spruce and sound hemlock, respectively were taken from the laboratory records for purposes of comparison.

YIELD OF PULP

The yield of screened sulphite pulp obtained from the decayed spruce woods did not vary greatly from each other, except in one case, nor were they much lower than the yield from sound spruce. The exceptional yield, which was abnormally low, was that from the rejected wood, No. 2541. None of the hemlock woods was sufficiently decayed to show a pronounced decrease in yield. The aspen pulps showed a lesser yield with greater amount of decay.

523°—25†——2

TABLE 4.—*Soda cooks of sound and decayed woods*

[Yield percentages are based on oven-dry weights of wood and pulp]

Sample No.	Cook No.	Pulp No.	Description	Maximum steam pressure	Time at maximum pressure	Total time of cook	NaOH per 100 pounds oven-dry chips	Liquor per 100 pounds oven-dry chips	Alkali consumed	Yield of crude pulp	Yield of screenings	Yield of screened pulp
				Lbs.	*Hrs.*	*Hrs.*	*Pounds*	*Gallons*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
-------	109	540	Sound spruce	100	½	2¼	20.3	27.4	75.9	50.2	1.4	48.8
2560	6	2559	Decayed spruce.	100	5	6	20.5	31.6	89.9	42.6	-------	42.6
2541	7	2557	do	100	5	6	20.5	31.7	95.9	48.8	16.8	32.0
-------	228	40	Sound hemlock.	105	¾	4¾	20.5	27.2	82.0	46.0	0.1	45.9
2542	3	542D	Decayed hemlock.	100	5	6	20.5	31.4	-------	45.5	-------	45.5
2552	4	552D	Decayed aspen.	102	4¾	5¼	26.2	30.3	95.3	44.0	4.9	39.1

In the soda process the yields of spruce pulps showed a wider range than those for sulphite, with the rejected spruce wood again giving an abnormally low yield. The aspen wood, No. 2552 (pulp No. 552 D), yielded only 39.1 per cent, notwithstanding the use of an exceptionally large proportion of chemical. Badly decayed wood is soluble to a high degree in caustic soda solution, so much so that during the early stages of cooking the concentration of the active alkali is reduced to such an extent that the pulping process can not be completed. The result is a large percentage of screenings and a low yield of screened pulp. For example, the badly decayed spruce wood, No. 2541, was soluble in caustic soda (see Table 7) to the extent of 62.3 per cent. It was found by repeated trials that the 20.5 pounds of alkali sufficient to pulp 100 pounds of sound wood was insufficient for this decayed spruce, the yield from which (pulp No. 2557) consisted of 16.8 per cent of screenings and only 32.0 per cent of screened pulp.

Attention should be directed to the fact that these yields are expressed on an oven-dry weight basis both for the wood and the pulp. *If it had been possible to convert the yields to a pounds-per-cord basis, a distinct lowering of yield with increasing decay would doubtless have been evident even in the less extreme cases.* Such a conversion involves two factors: The density of the wood, and the solid wood volume per cord. Both factors, even for sound wood, show wide variation, so that any figures given for the yield per cord would be practically meaningless. If solid volume, rather than the number of cords, be taken as the basis, then density becomes the chief factor to be considered; and of two woods of different densities but yielding equal weights of pulp, that with the lower density will, obviously, show the lower yield per unit volume.

Comparisons on that basis would be fairly exact but for the fact that data on the density of the woods used for the pulping tests are insufficient, and in some cases apparently conflicting; nevertheless they indicate, in general, that the progress of decay is accompanied by a decrease in density. This is certainly true in the advanced stages of decay, and the decrease in average density is doubtless roughly proportional to the increase in decay. Further investigation of this point would be very desirable because of its direct and vital bearing upon mill operation.

The decayed aspen used in the tests weighed approximately 2 pounds less per cubic foot than sound wood. To put the matter in another way: If 100 solid cubic feet of sound aspen had been purchased and placed in storage until decay had reduced its density to this extent, 200 pounds of wood would have been lost; and even though a yield (on the weight basis) were obtained equal to that for sound wood, say 40 per cent, the actual loss of 80 pounds per 100 cubic feet would be there just the same.

QUALITY OF PULP

The screened pulps from both the sulphite and the soda cooks were converted into waterleaf paper on the experimental paper machine, and the papers were tested for strength. The data appear in Table 5.

TABLE 5.—*Strength tests of sulphite and soda pulps made from sound and from decayed woods*

Sample No.	Cook No.	Description	Weight of ream, 24 by 36—500	Mullen test	Points per pound per ream	Breaking length	Folds	Stretch	Atmospheric conditions: Relative humidity	Atmospheric conditions: Temperature
		Sulphite pulp:	*Pounds*	*Pounds*		*Meters*	*Number*	*Per cent*	*Per cent*	*° F.*
2540	336	Sound spruce	43. 5	32. 0	0. 74	5, 880	785	2. 90	65	94
2547	7	Decayed spruce	41. 5	26. 8	. 65	5, 480	310	1. 58	64	92
560A	8	Do	39. 5	25. 4	. 64	5, 630	121	1. 88	64	92
560	10	Do	38. 0	25. 4	. 67	6, 040	207	1. 69	64	77
2548	6	Do	38. 0	25. 9	. 68	5, 070	169	1. 83	64	92
2555	9	Do	30. 0	17. 8	. 59	4, 370	26	1. 62	64	93
554	4	Sound hemlock	47. 6	32. 2	. 68	6, 660	449	3. 46	66	75
542A	2	Decayed hemlock	37. 0	14. 7	. 40	4, 490	137	1. 90	67	72
542B	3	Do	39. 5	25. 8	. 65	6, 170	232	2. 54	65	75
542C	5	Do	38. 5	21. 7	. 56	5, 950	306	2. 58	66	75
50	351	Sound aspen	51. 2	25. 6	. 50	3, 970	12	1. 87	65	74
5521	1	Decayed aspen	44. 5	11. 4	. 26	3, 760	5	1. 66	66	68
		Soda pulp:								
540	109	Sound spruce	40. 0	28. 8	. 72	5, 490	707	1. 97	65	--------
2559	6	Decayed spruce	46. 0	21. 0	. 46	4, 770	192	1. 44	65	79
2557	7	Do	76. 5	25. 2	. 33	2, 790	1	1. 08	66	82
40	228	Sound hemlock	43. 5	37. 3	. 86	6, 390	668	3. 26	68	69
542D	3	Decayed hemlock	46. 5	24. 3	. 52	5, 380	389	3. 32	64	77
552D	4	Decayed aspen	40. 5	11. 8	. 29	3, 290	4	1. 64	65	72

All of the pulps made from decayed woods show a lower strength than those made from sound wood, as indicated by the bursting and breaking-length tests. The breaking length for pulp No. 560, from decayed spruce, was the only exception to this rule. The low endurance of folding shown by the pulps from decayed woods is very marked, and is indicative of the decidedly deteriorating effect which decay in wood has upon the flexibility and wearing qualities of pulps made from it. This deterioration is especially marked in sulphite pulp No. 2555, made from the badly decayed spruce wood. Moreover, the pulp was exceptionally dirty. When this same wood was cooked by the soda process the strength of its pulp, No. 2557, was even lower, and the pulp was again very dirty in color.

CHEMICAL PROPERTIES OF SOUND AND DECAYED WOODS AND PULP FROM SOUND AND DECAYED SPRUCE

A knowledge of the chemical composition of sound woods and pulps and of the changes produced in them by the action of fungi is of considerable importance to an understanding of the losses sustained during the storage of such material and in the conversion of wood into pulp and of pulp into paper. In following the earlier stages of decay, in particular, chemical analysis is superior to visual examination, for an infected log or lap of pulp may look relatively sound and yet contain wood-destroying fungi which had chemically changed the fiber, rendering it of distinctly less value as a paper-making material. For these reasons sound and decayed specimens of spruce, hemlock, balsam, and aspen woods and of pulps from sound and decayed spruce were subjected to chemical analysis, the object of the investigation being to correlate, more definitely than ever before, and quantitatively where possible, the chemical evidences with the fact and the degree of wood and pulp decay.

The analytical methods used were those that have been found of value in the study at the laboratory of the chemistry of woods, details of procedure having appeared in the technical journals in various articles[3] initiated by the laboratory. The methods cover determinations for moisture; ash; solubility in cold water, in hot water, in 1 per cent NaOH, in 7.14 per cent NaOH, in alcohol, and in ether; lignin; cellulose; alpha, beta, and gamma cellulose in the total cellulose; pentosans; methyl-pentosans; and copper number.

SPRUCE WOOD AND SPRUCE MECHANICAL PULP

SOUND SPRUCE WOOD

In order to establish a check in the present studies, cross sections of spruce logs were obtained from various parts of eastern North America and analyzed for lignin, cellulose, and solubility in ether and in alcohol. These data, together with the number of annual rings in each log sampled, are recorded in Table 6. The samples were inspected microscopically and found to be sound, except as indicated in the table. The lignin showed variation from 26.8 per cent to 28.3 per cent, and the cellulose from 58.1 per cent to 61.7 per cent. Whether these variations are indicative of differences due to the locality of growth it is impossible to say from the limited data. All of the Canadian and New England samples tested were relatively high in cellulose content, and those from Wisconsin and lower Michigan relatively low. The decayed spruce woods studied were mostly from Wisconsin. If locality were known to exert an influence on cellulose content, the average of the values for cellulose given in Table 6 would be too high for general comparison, and losses in cellulose due to decay would be over-accentuated. The more conservative value, 58.5 per cent, obtained for the Wisconsin sample designated VA was therefore chosen as a standard for comparison.

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[3] Schorger, A. W., Jour. Ind. and Eng. Chem. 9: 556. 1917.
Mahood, S. A., and Cable, D. E., Jour. Ind. and Eng. Chem. 12: 873. 1920.
Mahood, S. A., and Cable, D. E., Jour. Ind. and Eng. Chem. 14: 727. 1922.
Bray, M. W., and Staidl, J. A., Jour. Ind. and Eng. Chem. 14: 35. 1922.

TABLE 6.—*Chemical analyses of samples of sound white spruce wood from various parts of North America*

Designation of sample	Company and locality	Moisture	Lignin	Cellulose	Ether soluble	Alcohol soluble	Number of annual rings	Condition as observed under microscope
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. in.*	
VIIC	Port Huron Sulphite & Paper Co., Edmonton, Alberta, Canada.	3.3	26.8	61.7	0.7	0.4	64	Occasional thread of mycelium.
VIIIB	Riordon Co. (Ltd.), Hawkesbury, Ontario, Canada.	4.5	28.0	61.1	.7	1.0	110	Do.
XIIIB	Price Bros. Co. (Ltd.), Kenogami, Quebec, Canada.	5.0	27.4	60.9	1.5	.9	23	Sound.
XB	Laurentide Co. (Ltd.), Grand Mere, Quebec, Canada.	4.9	28.1	60.5	1.5	.9	40	Do.
VIA	Groveton Paper Mills Co., Groveton, N. H	5.0	28.1	60.7	.8	1.1	47	Do.
IVA	S. D. Warren Co., Cumberland Mills, Me.	4.4	26.9	60.1	.6	.8	75	Do.
Id and Ig	Pejepscot, 10 miles north of Brunswick, Me.	4.2	26.8	59.7	.6	.8	18	Do.
IXA	Hammermill Paper Co., Fort William, Ontario, Canada.	3.6	27.6	59.3	.7	1.1	85	Do.
VA	Marathon Paper Mills, Rothschild, Wis.	3.1	28.3	58.5	1.2	.8	80	Do.
IIIA and bx	Fletcher Paper Co., Alpena, Mich.	4.2	27.9	58.1	.9	1.0	27	Occasional thread of mycelium.

DECAYED SPRUCE WOOD

Spruce woods, Nos. 2545, 2546, and 2541, previously described in connection with the pulping tests and representing decay in increasingly advanced stages, together with two additional samples, were analyzed by the methods used for the sound wood VA. The additional samples were No. 2549, a Minnesota wood nearly free from decay, and No. 2556, a Minnesota deadhead log taken from the bottom of the river. In Table 7, following the data for sound wood VA, are presented the data for decayed woods, arranged in the order of decreasing cellulose content. This is also the order of increasingly advanced stages of decay as evidenced by the general appearance of the specimens. Of the five, however, only No. 2541 was so far gone that it had been rejected at the mill.

TABLE 7.—*Analyses of sound and decayed spruce woods*

Sample No.	Description	Cold water soluble	Hot water soluble	Ether soluble	1 per cent NaOH soluble	7.14 per cent NaOH soluble	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash.
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
VA	Sound spruce, average	2.2	3.8	1.2	8.8	18.9	4.1	28.3	58.5	63.5	10.4	26.1	11.8	1.8	0.17
2556	Deadhead	1.4	1.3	0.5	12.0	19.7	5.9	30.9	59.5	60.0	16.1	23.9	9.8	2.8	.45
2549	Very slightly decayed	3.4	5.6	1.5	15.0	24.0	5.5	30.6	54.6	----	----	----	----	----	.38
2545	Slightly decayed, top of pile, mill run	4.1	6.3	1.7	20.6	28.5	7.7	30.5	54.1	42.8	37.7	19.5	11.3	1.6	1.37
2546	Considerably decayed	5.5	9.7	1.3	39.9	49.2	17.4	35.2	46.9	27.8	61.4	10.8	9.4	2.6	.75
2541	Badly decayed	6.5	11.9	1.4	50.2	62.3	23.5	38.2	42.0	17.0	74.6	8.4	8.5	3.7	.61

The deadhead log, No. 2556, contained a larger proportion of cellulose than did the sound wood. This condition is at least partially accounted for by the fact that it had been stored under water and the water-soluble material had been more completely removed. If the cellulose content of both samples be calculated on the basis of the residue after the removal of the hot-water-soluble portion, No. 2556 gives a slightly lower value than VA. In any event, the conclusion may be drawn that the log stored under water, and therefore out of contact with the air, had not suffered appreciable decay.

The stability of the cellulose isolated by the Cross and Bevan method is greatly decreased as measured by the resistance to the action of 17.5 per cent NaOH. This resistance is indicated by the proportions of alpha, beta, and gamma cellulose.

Both the cold-water-soluble and the hot-water-soluble content of these woods increased with increase in decay.

An even greater indication of increasing decay is afforded by the increase in solubility of the wood in caustic soda. The results obtained with 7.14 per cent NaOH appear to differ from those obtained with 1 per cent NaOH only in intensity. Even in wood which has not reached a sufficiently advanced stage of decay to be rejected for pulping, the solubility in 1 per cent NaOH has risen to 39.9 per cent, as compared with 8.8 per cent for sound wood. The copper number also increases with increased decay, but its changes during the earlier stages are not so pronounced.

The process of decay does not appear to have destroyed the lignin. In fact, the proportion of lignin increased as decay advanced. This increase can readily be explained, however, without assuming the formation of lignin, provided it is assumed that an actual loss in weight of wood substance occurs during decay. In this way the lignin, unchanged in weight, represents a larger and larger proportion of the residual wood. The decrease in wood density, already referred to, and the action of isolated fungi, described later, fully substantiate the assumption.

Pentosans showed a decrease and methyl pentosans an increase; but the significance of these changes is not yet clear.

The resins, as determined by solubility in ether, and the mineral content, as determined by the ash, were not appreciably affected by the process of decay.

ANALYSES OF MECHANICAL PULPS MADE FROM SOUND AND FROM DECAYED SPRUCE WOODS

Mechanical pulps Nos. 1AA and 2AB, ground respectively from sound wood No. 1 and decayed wood No. 2546, were chemically analyzed. The data are found in Table 8. The data for pulp No. 1AA, Table 8, closely resemble those for sound wood VA in Table 7. The small difference becomes even less significant when note is taken of the low water solubility of the pulp, due to the removal of a large proportion of the water-soluble content during the pulping process. On the other hand, in a comparison of the respective data for pulp No. 2AB and wood No. 2546, the decrease in water solubility is not sufficient to account for the more significant decrease in copper number, lignin, and solubility in NaOH, and for the increase in cellulose content. *If account is taken, however, of the brashness and brittleness of the decayed wood and of the abnormal losses in the white water, it* *may be assumed that the grinding process pulverized to a large extent the portion of wood which had suffered decay, and that after the removal of this finely divided matter, as well as the water-soluble products, the residual pulps had more nearly the properties of pulp made from sound wood.*

TABLE 8.—*Analyses of spruce groundwood pulp*

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p. ct. NaOH soluble	7.14 p. ct. NaOH soluble	Copper number	Lignin.	Cellulose.	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1AA	From sound wood No. 1	0.0	1.0	0.4	10.1	18.3	4.4	29.7	60.0	60.5	24.5	15.0	11.9	2.0
2AB	From decayed wood No. 2546	.6	1.4	.8	17.7	27.4	6.6	29.7	59.6	58.7	20.7	20.6	10.3	2.6

HEMLOCK, BALSAM, AND ASPEN WOODS

Chemical analysis was made of sound and decayed hemlock woods, Nos. 2554 and 2542, and of decayed aspen wood, No. 2552, all previously described in connection with the pulping tests. A sample of aspen, No. 2551, freshly cut at Madison, Wis., was analyzed as representative of sound wood. Sound balsam wood, No. 2550, from Minnesota, and decayed balsam wood, No. 2553, from Wisconsin, were also analyzed.

The results are shown in Table 9. That none of these cases had reached a very advanced stage of decay is substantiated by the relatively small difference between the data for the sound and the affected material. Further substantiation is found in the results of the chemical pulping tests of the hemlock, already described, in which very little difference appeared in the yields obtained from the two stakes of this wood. (See Tables 3 and 4.) The effect of decay is evidenced by increased solubility in water and in NaOH, and by decreased stability of the cellulose as measured by the alpha, beta, and gamma cellulose. Mechanically, it is reflected in the decreased strength of both the soda and the sulphite pulps. In the case of the sound aspen, since the material that was pulped (see Table 3) was not the same as that analyzed, the pulping and analytical data are not directly comparable. The similarity of the analytical data for the two states of the wood suggests, however, that decay had not reached an advanced stage in No. 2552.

TABLE 9.—*Chemical data on sound and decayed hemlock, aspen, and balsam*

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p. ct. NaOH soluble	7.14 p. ct. NaOH soluble	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2554	Sound hemlock	2.9	4.1	0.5	14.5	21.6	7.3	35.8	50.6	57.6	24.4	18.0	9.0	2.7	0.7
2542	Decayed hemlock	4.8	6.0	.7	20.2	29.0	8.2	31.0	53.4	51.8	29.2	19.0	6.7	6.6	.8
2551	Sound aspen	2.6	3.5	2.1	20.8	33.9	4.8	26.6	57.5	58.3	23.3	18.4	18.9	.2	.8
2552	Decayed aspen	3.4	4.7	1.7	24.1	32.7	5.8	26.3	55.9	55.5	28.6	15.9	18.3	.0	1.0
2550	Sound balsam	.5	1.3	1.0	10.1	18.0	6.1	31.5	50.5	58.5	18.0	23.5	10.2	2.4	.4
2553	Decayed balsam	6.5	9.4	.7	22.8	30.6	8.3	30.5	52.8	54.8	27.4	17.8	9.1	2.6	1.2

Sound and decayed balsam Nos. 2550 and 2553 were selected at random from mill piles. Like the hemlock, the balsam showed a higher cellulose content in the decayed material than in the sound. The true evidence of decay is seen, however, in the increase in copper number and solubility in water and in NaOH, and in decreased stability of the cellulose. Unfortunately, it was not practicable to make pulping trials on the balsam woods.

SPRUCE SULPHITE PULP

Spruce sulphite pulps Nos. 2547, 560, 2548, and 2555, prepared from woods containing successively increasing amounts of decay, were chemically analyzed, with results as shown in Table 10. The data as to cooking and physical properties of these pulps are those previously given in Table 3. The chemical data for pulp No. 2561 are taken from records of work done previous to these studies, and are representative of pulp made from sound spruce.

TABLE 10.—*Analyses of sulphite pulps from spruce woods*

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p. ct. NaOH soluble	7.14 p. ct. NaOH soluble	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash
		P.ct	*P.ct*	*P.ct*	*P.ct*	*P.ct*		*P.ct*	*P.ct*	*P.ct*	*P.ct*	*P.ct*	*P.ct*	*P.ct*	*P.ct*
2561	From typical sound wood	0.1	0.0	1.1	11.0	20.8	3.0	1.2	97.2	87.5	3.2	9.3	3.5	0.8	0.29
2547	From slightly decayed wood No. 2545	.0	.0	1.5	10.8	24.8	2.6	2.8	96.1	75.8	17.9	6.3	4.6	.6	.57
560	From somewhat decayed wood No. 2560	.3	.0	1.3	14.3	28.2	3.8	1.5	96.5	79.4	11.4	9.2	4.2	.9	.33
2548	From considerably decayed wood No. 2546	.0	.0	1.0	13.4	31.3	3.7	2.1	96.1	73.0	22.0	5.0	3.6	1.4	.50
2555	From badly decayed wood No. 2541	.3	5.0	.9	31.9	52.8	9.0	1.7	94.4	46.1	48.6	5.3	2.9	1.4	.81

The pulps did not vary greatly in purity. None, with the exception of No. 2555, contained less than 96.1 per cent cellulose, and none more than 2.8 per cent lignin. The progressively increased degree of decay in the woods was clearly reflected in the pulps, however, by the increase in their solubility in NaOH and the decrease in stability of the cellulose. The copper number did not show any marked increase, except in the one case of advanced decay.

SPRUCE SODA PULP

Soda pulps Nos. 2559 and 2557, prepared, respectively, from slightly and badly decayed spruce, the same lots from which were made sulphite pulps Nos. 560 and 2555 (Table 10), were analyzed, and the data are given in Table 11.

The low cellulose and high lignin in pulp No. 2557 indicate clearly its undercooked condition, which was evidenced also by the large proportion of screenings, 16.8 per cent, and by the weak, brittle condition of the screened pulp. It is not surprising to note, therefore, that this pulp was still soluble in alkali to a considerable degree. Pulp No. 2559 also appears far from pure, containing as it does 9.6 per cent lignin and only 89.4 per cent cellulose.

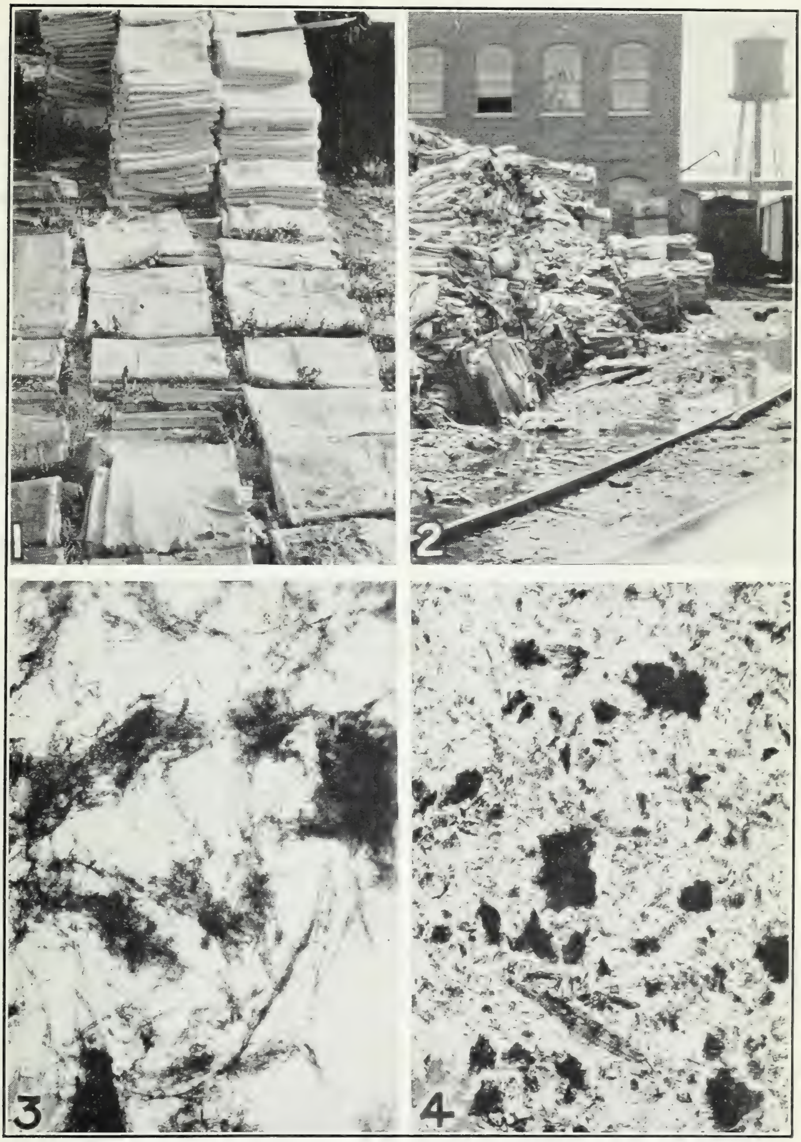

FIG. 1.—Ground-wood pulp stored in a wood yard on low swampy ground supporting a dense growth of grass and weeds. Sawmill slabs are used for a base. This is extremely poor practice. Conditions probably could not be worse for decay at the bottom of the piles

FIG. 2.—Pile of ground-wood pulp on swampy ground. Note the surface water all about the pile. This yard should have been drained and surfaced with cinders before use for storage purposes

FIG. 3.—Fibers of sound ground-wood pulp

FIG. 4.—Fibers of decayed ground-wood pulp. Note how the fibers have been broken up into short fragments through the action of wood-destroying fungi

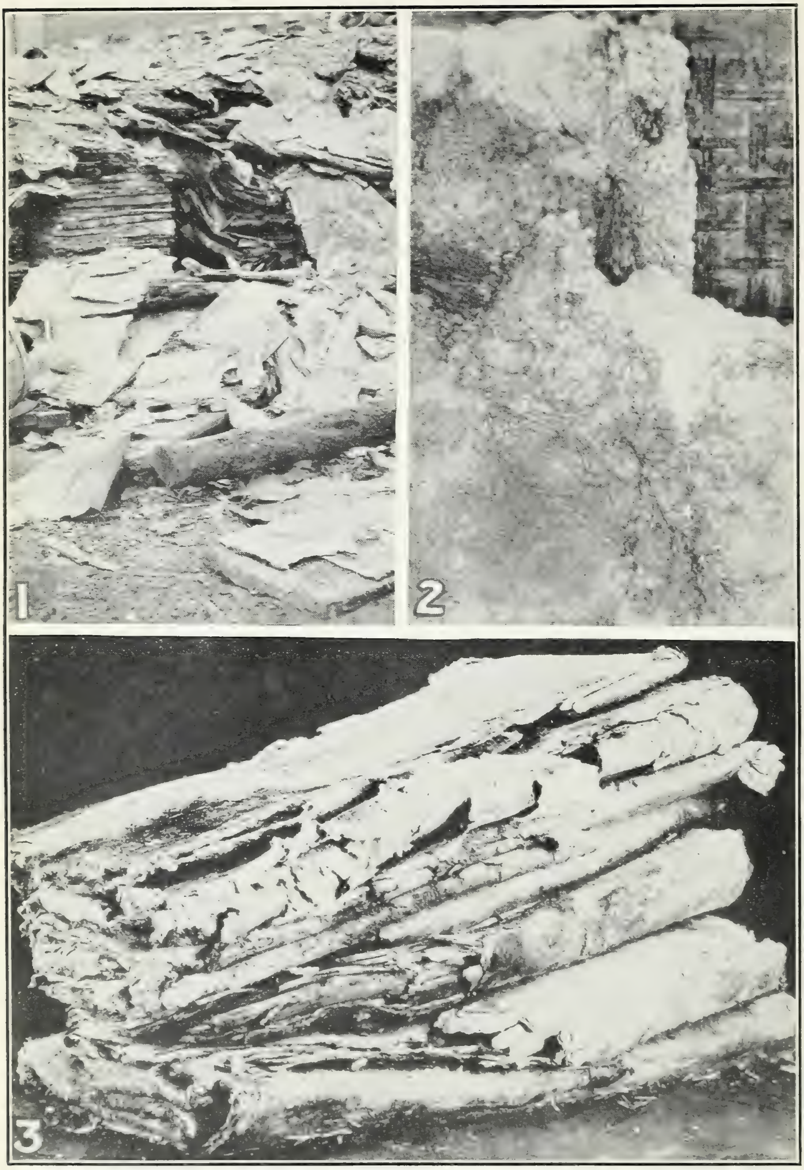

FIG. 1.—Base of a pile of Canadian hydraulic-pressed ground-wood pulp worthless from decay after three years' storage on an open platform. The pile was originally 20 feet high and contained 7,500 tons. More than $10,000 worth of this pulp was an absolute loss

FIG. 2.—Lap taken from near the base of the pile shown in fig. 1, showing brown strand-like mycelium of a fungus

FIG. 3.—Several laps of ground-wood pulp deteriorated by wood-destroying fungi during a six months' storage period in a mill basement

In view of the incompleteness of the alkaline pulping action, it is doubtful whether the chemical data for these pulps has much significance with regard to decay in the wood.

TABLE 11.—*Analyses of spruce soda pulps*

Sample No.	Description	Cold-water soluble	Hot-water soluble	Ether soluble	1 p.ct. NaOH soluble	7.14 per cent NaOH solub.	Copper number	Lignin	Cellulose	Alpha cellulose	Beta cellulose	Gamma cellulose	Pentosan	Methyl pentosan	Ash
		P. ct	*P. ct*	*P. ct*	*P. ct*	*P. ct*		*P. ct*	*P. ct*	*P. ct*	*P. ct*	*P. ct*	*P. ct*	*P. ct*	*P. ct*
2559	From slightly decayed spruce No. 2560[1]	0.8	0.2	1.0	3.2	6.6	2.6	9.6	89.4	57.1	39.1	3.8	7.8	0.7	1.17
2557	From badly decayed spruce No. 2541	.6	.0	.7	7.0	13.6	7.9	38.3	56.4	23.3	69.7	7.0	4.5	2.7	2.08

[1] Decayed spruce wood, sample No. 2560, was not analyzed, but was comparable to spruce No. 2545. (See Table 7.)

GENERAL DISCUSSION OF CHEMICAL DATA

Even the limited amount of data obtained in this study clearly indicates the value of chemical analysis as an aid in studying the progress of decay and its effect upon yield and quality of pulp. The analytical tests which seem to offer the greatest promise in this direction are tests for cellulose content and for solubility in water and in 1 per cent NaOH, together with possible determinations of alpha, beta, and gamma cellulose. It is not unlikely that a quantitative relation between some or all of these values and the degree of decay, as evidenced by the pulping value of the wood, can be worked out for the different species. A qualitative parallelism at least, has been clearly demonstrated for spruce woods, and this persists in the mechanical and sulphite pulps made from them. The tests for solubility in hot water and, especially, in 1 per cent NaOH are easy to apply, and ought to prove correspondingly valuable. The determination of total cellulose content, and of alpha, beta, and gamma cellulose, are more difficult operations, and are not likely to afford much information beyond confirmation of the results indicated by the solubility tests. Furthermore, relatively small amounts of decay appear to be reflected with greater definiteness by the solubility in alkali than by any of the other tests.

STORAGE OF PULP

Chemical pulps, as a rule, are stored indoors. Ground wood, on the other hand, is often stored in the open in large, compact piles up to 20 or 30 feet high (Pl. X, fig. 1). It is also stored in unheated closed sheds, or in the warm basements of the mills. It contains about 70 per cent moisture as it comes from the wet machines. Occasionally it is piled on concrete bases; more often it is piled on planks or slabs (Pl. X, fig. 2) which are commonly infected with wood-destroying fungi and ready to transmit the infection to the stock. (See Pl. X, fig. 3.) In some cases it is piled directly on the ground, or on older, sometimes badly infected, pulp. (See Pl. X, fig. 4.) For lack of suitable storage space, piles are often placed on low, swampy ground amid a luxuriant growth of grass and weeds. (See Pl. XI, fig. 1.) In some instances piles are placed in poorly kept wood yards (Pl. XI, fig. 2) surrounded by rotting débris and subject to abundant infection from fungi.

Storage in unheated sheds, which naturally affords protection against weathering and soot, and partial protection against air-borne spore infections, probably does not protect against deterioration by fungi after infection has actually taken place. Where pulp is preserved with a volatile antiseptic, a closed building would be of advantage in retaining the vapors.

Pulp piled in warm, moist basements will be especially subject to deterioration, and it should not be held under such conditions longer than is absolutely necessary.

LENGTH OF STORAGE

Because of manufacturing conditions, a rather long storage period is in many cases necessary for ground wood pulp. A large volume of this pulp is ground by hydroelectric power, the supply of which is dependent on stream flow. Thus, at many mills, production becomes seasonal and must be concentrated at favorable times; and storage of large quantities of material, for both local consumption and shipment, becomes necessary over periods of from 6 to 12 months or even longer.

Chemical pulps are for the greater part converted into paper immediately, or within a few months.

DETERIORATION DURING STORAGE

Molds and wood-destroying fungi are the chief enemies of pulp. Molds cause physical deterioration by (1) discoloring the pulp, and (2) binding together the particles so that the molded spots or areas do not beat up well—a lumpy, speckled paper resulting. Wood-destroying fungi decrease the strength of the wood fibers and make them so brittle that they break into short lengths (Pl. XI, figs. 3 and 4) in the beater, with the result that much of the pulp is lost in the white water and the manufactured paper has little strength. The combined action of molds and wood-destroying fungi results in the production of paper of a very poor color and quality.

The losses during the storage of pulp may be large. They depend upon the length of the storage period and the conditions under which the pulp is stored.

Chemical pulps, in ordinary commercial practice, deteriorate much less than do ground-wood pulps, owing to their shorter storage period and the complete sterilization which takes place during the process of cooking. Molds, however, which are more likely to develop than decay organisms, may cause more or less trouble in the manufacture of the better grades of paper; and in extended periods and poor conditions of storage both decay and molding may become just as severe in chemical pulps as in ground wood. For a further discussion see Blair (*6*).

A rather common belief among pulp manufacturers is that the more sulphite liquor the pulp retains the more rapid will the pulp deteriorate during storage. A few tests were conducted at the laboratory in an attempt to find out something on this point. While not conclusive, the tests at least indicated that traces of sulphite liquor remaining in the pulp do not hasten the deterioration caused by fungi.

The writers have had very little opportunity to observe deterioration in hydraulic-pressed ground wood, but the information at hand indicates that pulp so treated will not offer any greater resistance to decay than the wetter laps. This is to be expected, as the pressed pulp still contains 40 to 55 per cent moisture. The case already cited of a total loss in a portion of a 7,500-ton pile (Pl. XII, figs. 1 and 2) after storage for somewhat less than three years is strong evidence on this point.

Several writers have expressed opinions as to the sources of fungous infection in fresh pulp. Some hold that infection in the wood carries over through the grinding process and continues to develop in the pulp. Acree (*1*), Beadle and Stevens (*4*) (with reference to blue stain caused by *Ceratostomella* spp.), and Klemm (*14*) have expressed themselves as inclining to this view. Blair (*5*) likewise states:

> The process of manufacture does not affect the fungus in any way except to separate it into a great number of small pieces which are distributed throughout the pulp. When such pulp is stored, each piece of the fungus may set up a center of decay within the pile whether of laps or of bales.

Sée (*23*), in discussing the molds that injure paper, remarks that—

> the germs of these true maladies of paper are not caused by any sort of later infection, but preexist in the pulp from which the paper is made, and probably proceed from the materials used in making paper pulp, such as straw, alfalfa fiber, etc.

In order to find out whether the infection in ground wood originates in the decayed wood used in its manufacture, an experiment was conducted, the material used being pulp freshly ground from decayed spruce at one of the cooperating mills.

The wood used was abundantly infected with *Fomes roseus*, *Lenzites sepiaria*, *Polystictus abietinus*, *Stereum sanguinolentum*, and *Trametes pini*.

The rots were not so far advanced but that the mycelium of each of them should have been alive in all cases. Culture tests proved this to be true, for *Fomes roseus* and *Stereum sanguinolentum* at any rate. Samples of the ground wood were collected in sterile bottles as the pulp left the grinder. A number of samples from freshly ground, commercially sound wood were also collected. The temperature at the discharge varied fron 120 to 180° F. (49 to 82° C.). At the surface of the stone, however, the temperature was much higher, and it should be noted that very minute particles of the fungus were for a short time exposed to this heat.

None of the samples, either from commercially sound or from decayed wood, produced a single wood-destroying fungus when plated out into Petri dishes on malt agar. Some plates remained sterile, but the remainder were overrun with molds, such as *Trichoderma* spp., normally obtained from river water. As many plates were sterile among those representing the infected wood as there were among those representing the sound wood. No difference could be observed in the species of molds obtained on the two groups of plates, a condition which would indicate that water, and perhaps air, are the sources of infection.

Considerable amounts of each sample were planted upon sterilized clean ground-wood pulp (approximately 70 per cent wet) supported over water in fruit jars. These cultures were kept for more than a year in an inside basement room in which the temperature was fairly constant (19 to 24° C.). In no case did infection by wood-destroying fungi occur. The remaining amounts of the samples were kept in the original containers, which were capped with cotton and cloth. After 14 months no evidence of hymenomycete infection had appeared, although most of the samples were infected with one or two species of molds.

This experiment is at least an indication that no infection from the rotten wood is carried through the grinding process. Undeniably, pulp made from infected wood does deteriorate faster in storage than that made from sound wood. (See Table 12.) This tendency would seem to be due to an increased susceptibility to infection rather than the bodily transfer of fragments of fungi from the wood.

Woody or other organic materials infected with living fungi are, however, a common source of infection—a fact which is particularly noticeable with decay-producing fungi. Barnes (*2*) placed rotten pulp in sound pulp and incubated the bundles for several weeks. The results led him to believe that the infection would not be transmitted. This opinion is not supported by repeated observations of what actually takes place in commercial storage. Pulp may become infected not only by contact with infected pulp but also by contact with other decayed materials. Rotten wood floors in storage sheds and plank bases for pulp piles frequently infect pulp placed in contact with them, and the infection may pass upward through a considerable number of laps. Any infected wood placed within or in contact with a pile may spread decay. An interesting demonstration of such contagion occurred in one of the experimental piles, where certain planks picked up about the yard were used to separate the experimental material from surrounding mill stock. At the end of six months an infection with a wood-destroying fungus could be traced from the planks downward through as many as eight laps.

The dirt carried on workmen's shoes and clothing is also a likely source of infection. The soil about pulp mills is loaded with fungi, and even small quantities transplanted to fresh, moist pulp are bound to start infections, each of which may eventually involve several hundred pounds of pulp. For this reason it would be highly advisable for each workman handling pulp to keep a pair of clean shoes for use on the pile only, and never to wear them anywhere else. Upon attention to just such details, to the layman apparently of little import, have been built up the highly successful practices of modern medical sanitation.

There still remain two other possible sources of infection to be considered: Contaminated water used in the manufacturing processes, and fungous spores carried by the air.

Beadle and Stevens (*4*) hold that little infection comes from the water. They advance the idea that infection depends upon the food-yielding capacity of the wood, which varies with the season of cutting; that in the spring and summer the wood contains, in the pith rays, sugars and other organic food materials which are favorable to mold growth; that in the fall these foodstuffs are converted into insoluble reserve substances, such as starch, which are less available as food for fungi; and that the only part water plays in the contamination of ground-wood pulp, aside, of course, from furnishing the requisite moisture, is in its reaction upon the foodstuffs in the wood, rendering the organic substances more or less available for the growth of fungi according to its softness or hardness. They also attribute to the mineral and nitrogenous substances in the water the possible function of nourishing the molds in their early development.

Barnes (*2*), on the other hand, points out the necessity of keeping pulp out of contact with pools of water, because "the more impurities an organic body contains, the greater tendency there is for that body to decay." Sée (*23*) maintains that water used in manufacture is at least one source of infection, and in this Wolesky (*27*) concurs. Sée also remarks that in considering the molding of paper the sizing should be viewed with suspicion.

After examining a large number of laps of pulp one becomes impressed with the fact that much of the infection is internal; that is, that many of the infected spots or areas originate within the laps. The decay has apparently been introduced through the water or through the air. Since many of the molds and two of the wood-destroying fungi commonly found on pulp have been isolated from river water used for manufacturing pulp, the inference is drawn that water probably plays a considerable part in infection.

Air-borne infections must also play their part. All of the fungi produce spores that are more easily carried about by air currents than the finest dust. In the case of the wood destroyers not only do the fruit bodies produce an abundance of spores, but in some cases the mycelium may also develop them. The mature spores germinate readily on any moist surface; if they happen to fall on pulp they are likely to start new infections which may spread rapidly. For this reason, rotting wood or pulp should not be left in close proximity to new pulp piles. As for mold spores, they are everywhere in the air (*6*) but of course are more abundant where there are large amounts of organic matter in a state of partial decomposition.

To prevent deterioration in stored pulp from the action of fungi and bacteria, then, the sources of infection should be eliminated so far as possible. Wood foundations for piles should be replaced with concrete or antiseptically treated lumber. The yards or sheds should be cleaned of infecting débris. Workmen should use care to keep infecting materials out of the piles. The water used in manufacturing processes should be filtered and sterilized if possible. These precautions will all aid in maintaining the pulp in good condition, but for complete protection it will also probably be necessary to introduce an antiseptic into the pulp itself.

PHYSICAL PROPERTIES OF PULP DECAYED IN STORAGE

In order to demonstrate the deterioration in the quality of mechanical pulps due to decay during storage, an experimental study of commercial pulps was made. One lot was stored at the mill and all the others at the Forest Products Laboratory.

The investigation began with two shipments of approximately 1,000 pounds each, designated A and B, from one of the cooperating mills. Shipment A had decayed during six months' storage (Pl. XII, fig. 3 and Pl. XVIII). Shipment B, submitted for comparison, consisted of freshly ground pulp. The cooperator described these pulps as follows:

One lot is freshly ground pulp from approximately 70 per cent spruce and 30 per cent balsam, ground at close to 70 horsepower with a 10-cut, screw-thread burr, at 160° F. The other pulp is of similar wood and similar grinding, except that it was stored for six months in a dark, high basement where it quickly became infected, as the laps show.

The decayed pulp was found to be very free, brash, and brittle, and in some of the badly decayed areas could be crumbled to a dust by rubbing between the fingers. The fiber length averaged 0.25 millimeters, as compared with 1.09 millimeters for the freshly ground pulp. (See Pl. XI, figs. 3 and 4.) Under as nearly identical beater and machine conditions as possible, both pulps, without the admixture of other fibers, were run into waterleaf paper on the laboratory machine. The decayed pulp ran much freer and also showed a tendency to stick to the couch and press rolls. It foamed badly, and this trouble was not overcome even with the addition of 2 per cent size and 2.5 per cent alum. Owing to the excessive amount of fine fiber, approximately 8.5 per cent more of the decayed than the sound pulp was lost in the white water.

The paper made from the decayed pulp was considerably darker than that from the fresh pulp. The difference, evident to the eye, was also clearly indicated by color readings on the Ives tint photometer, which gave for the decayed pulp 50.5 per cent white and 39.5 per cent black, and for the good pulp 60.5 per cent white and 23 per cent black. The paper from decayed pulp was much the dirtier, containing 20 times as many specks per unit area as the other. It possessed less than half the bursting strength and only about half the tensile strength, and was only one-tenth as resistant to ink penetration as the paper made from sound pulp.

Tests were then made, under more carefully controlled conditions, (1) to check the results obtained on pulps from shipments A and B, and (2) to determine the relative resistance of pulps made from sound and from decayed wood to decay in storage. Pulps in the form of commercial laps were stored at the Forest Products Laboratory in a room in which were maintained a high relative humidity and a temperature suited to the development of fungi.

A number of the laps were selected from pulps freshly ground from sound and from decayed spruce, data for which have been given in Table 2. They were designated as pulp No. 1AA, made from sound wood No. 1, and pulp No. 2AB, made from decayed wood No. 2546. Other laps were selected from a shipment of hydraulic-pressed pulp, No. 3AC, received from a Wisconsin mill. This material was in reasonably sound condition at the time the tests began; otherwise its history is not known. All the pulps were stored in the humidity room for a period of 12 months. In the same room during this period were stored 4,000 small laps of mechanical pulp which had been sprayed with disinfectants and inoculated with various molds and wood-destroying fungi, and also a large amount of badly decayed hydraulic-pressed pulp as a source of infection for the three pulps under observation. There was ample opportunity, therefore, for these to become thoroughly infected, as they did, during the test period.

At the end of approximately six months, and again at about the end of the year, some of the laps of each of the three pulps, so selected as to be as representative as possible of the state of decay throughout the lot, were made into waterleaf paper on the laboratory machine without the addition of other fibers.

The hydraulic pulp, and especially the pulp made from decayed wood, foamed very badly on the screen and paper machine. The pulp made from sound wood did not. Trouble on this account increased with the age of the pulp.

The papers from all three sources showed during storage an increase in freeness, a progressive darkening and yellowing, a loss in strength, and a decrease in the average length of the fibers.

The experimental data are given in Table 12. The color change, as measured by the Ives tint photometer, is indicated by a decrease in the percentage white and an increase in the percentage red plus green (yellow). The change was much more rapid in the samples from decayed wood. The bursting strength and the tensile strength in all cases showed a decided decrease, this effect being more rapid for the samples from decayed wood. The rate of weakening was higher during the first than during the second six months, a result which is in accord with the microscopical and chemical observations on these samples.

There was a marked difference in the amount of dirt and specks in the papers, those made from sound wood pulp being much cleaner.

TABLE 12.—*Physical properties of ground-wood pulps*

Sample No.	Description	Green sedimentation test. Overflow	Color (tint photometer)			Average length of fiber particles	Strength factors at 65 per cent humidity			
			White	Black	Red plus green		Weight of ream 24 by 36—500	Points per pound	Average breaking length	Average stretch
	From sound spruce:	*Cc.*	*Per cent*	*Per cent*	*Per cent*	*Mm.*	*Pounds*		*Meters*	*Per cent*
1AA	Freshly ground	91	68.5	20.0	11.5	1.5	47.0	0.30	2,780	1.4
1AA$_1$	After 6 months	100	67.5	19.8	12.7	.9	49.8	.27	2,340	.8
1AA$_2$	After 12 months	180	64.6	22.8	12.6	1.0	46.0	.22	2,175	1.3
	From decayed spruce:									
2AB	Freshly ground	100	62.5	27.5	10.0	1.4	48.0	.30	2,610	1.3
2AB$_1$	After 6 months	141	56.6	29.3	14.1	1.0	51.9	.21	1,990	.6
2AB$_2$	After 12 months	160	54.0	27.4	18.6	.7	47.0	.19	1,780	1.2
	Hydraulic pressed pulp:									
3AC	Freshly ground	------	------	------	------	------	------	------	------	------
3AC$_1$	After 6 months	132	66.0	23.3	10.7	1.1	46.0	.22	1,910	.6
3AC$_2$	After 12 months	170	59.8	26.0	14.2	1.0	47.0	.20	1,905	1.2

PRESERVATION OF PULP BY CHEMICAL TREATMENT

The chemical treatment of pulp is the most reliable method of preventing deterioration during storage, although to a considerable extent decay may be reduced by the methods of storage already recommended in this bulletin. Molding of pulp, however, appears to be more difficult to control than decay. Moist pulp, particularly ground wood, will prove highly susceptible to the attack of fungi (so long as the temperature is favorable to the growth of these organisms) unless their food supply is poisoned by the introduction of antiseptics.

If it were commercially feasible always to dry the pulp below the limits required for fungous growth, say to from 15 to 20 per cent, or, on the other hand, to keep it completely saturated, the problem would be largely solved. (See Blair and Parke-Cameron (*7*) for a discussion of under-water storage for mechanical pulp.)

WORK OF OTHER INVESTIGATORS

The writers are aware of only one reference in literature to attempts earlier than their own to preserve pulp from decay by the addition of antiseptics. This is a brief mention by Wolesky (*27*) of preliminary tests, from which he concludes that 0.25 per cent solutions of sodium chloride, magnesium sulphate, or aluminum sulphate applied on the wet machine would protect ground wood.

Concurrently with the present investigation, Bates (*3*) has discussed tests made at the Kenogami mill of Price Brothers & Co. (Ltd.), of Canada. This investigator reports spraying approximately 29 tons of wet pulp with three chemicals—zinc chloride, mercuric chloride, and sodium fluoride. The chemicals were applied as a water solution by means of a perforated brass pipe, which delivered about 5 pounds of solution per minute on a felt roll fitted to the top press roll. Zinc chloride was used in a 3 and a 7.15 per cent concentration, mercuric chloride in a 0.107 and a 0.428 per cent solution, and sodium fluoride in a 1.14 and a 2.86 per cent solution. Some solution was necessarily pressed out and lost in the white water.

After treatment most of the material was piled in a storage shed. For the first eight months it lay in separate exposed piles at one end of the building, in a cool location, and showed little change. Later the piles were transferred to the middle of the building and buried under the season's supply of pulp. After 12 months they were again inspected. In no case, even in the adjacent untreated pulp, was deterioration serious.

At the time the material was put into the storage shed about 20 laps treated with each preservative, together with 20 untreated laps for each, were placed in a closed, humid kiln of brick construction in the mill basement, where conditions for decay were very much more favorable. After 18 months this material was in a condition far different from that of the material placed in the shed. The laps with the light and the heavy zinc chloride treatments were badly discolored by black fungous spots scattered throughout the pulp, the effect being worse in the case of the heavier chemical treatment. Those treated with mercuric chloride, both light and heavy, were also badly discolored with green and gray mold patches, although the pulp was fairly well preserved from decay. Those from the sodium fluoride solution, however, were in strikingly good condition as compared with the untreated pulp, which was seriously molded and rotted. These tests pointed to the conclusion that sodium fluoride in 1.14 per cent concentration, applied at the rate of about 12 pounds per ton of air-dry pulp, or 4 pounds per ton of wet pulp having a moisture content of 72.7 per cent, probably may be used very effectively as a preservative for ground wood.

EXPERIMENTAL PROCEDURE

TESTS AT FOREST PRODUCTS LABORATORY

During the course of this study, 112 different chemical preservatives were investigated, with the object of finding an efficient one that could be applied to pulp at a reasonable cost.

About 3,000 small ground-wood laps and 1,400 sulphite laps were treated and tested under laboratory conditions, in addition to ground-wood pulp experimentally treated in the two mill tests described in the following section.

Laboratory procedure was in general, as follows: On a small wet machine there were run off laps of fresh pulp about 25 inches long, 12 to 14 inches wide, and one-eighth inch thick. After the laps had been trimmed to about 21 inches in length they were separated into bundles of 7 and 3. Each bundle was then weighed separately, and all 10 laps were afterwards spread out on a table and sprayed on both sides with preservative by means of an ordinary hand-operated 2½-gallon compressed-air garden sprayer.

Moisture determinations showed the ground-wood and sulphite laps to be about 30 and 25 per cent oven-dry, respectively, before spraying. Each piece of the lot containing seven laps was then inoculated by shaking on one surface from an atomizer bottle a heavy water suspension of the mixed spores of 25 molds. The three other laps were each inoculated in 10 places with mycelial cultures of five wood-destroying fungi grown on agar, small squares of the agar being cut out with the growing fungus. After inoculation each lot of seven and of three was folded once and then weighed for the second time in order to determine the amount of preservative in the pulp, the weight of inoculating substance being negligible.

The amount of pulp treated at the laboratory varied from 3 to 15 pounds, oven-dry weight, for each concentration applied. The concentration of solution used was to a certain extent limited by the solubility of the chemical; but where the antiseptic value was doubtful and the substance easily water-soluble in the desired amount, 5 per cent solutions were chosen for the preliminary tests. In later tests of substances which looked promising the concentrations, and hence the amount of antiseptic per unit of pulp, were in many cases reduced.

At the end of a day's run the bundles of laps were taken to a storage house (Pl. XIII, fig. 1) in which the air was kept highly humid and the temperature held at 72 to 75° F. The bundles of seven laps inoculated with molds were for the first few months stacked closely on narrow shelves, with one or more untreated laps separating the treated bundles, and with occasional bundles of untreated test laps interspersed at random to serve as checks or blanks. For the last 10 months of the test, however, the bundles were repiled with thick laps of very rotten hydraulic-pressed pulp separating the layers, so as to give a more severe infection. The bundles of three laps, inoculated only with wood-destroying fungi, were piled on other shelves and separated only by laps of clean, untreated pulp.

The increase of moisture content due to treatment varied, of course, with the amount of solution applied, but no records of this were taken at the time of spraying.

Very little drying seems to have occurred during storage, except in the case of a few laps at the top of the piles before they were interpiled with the decayed commercial ground wood. The average moisture for the 81 representative laps sampled at the time of the last inspection was approximately 71 per cent, varying for the individual specimens between 41 and 81. There were only 17 laps below 65 per cent, and 64 between 65 and 80 per cent.

COMMERCIAL TESTS AT MILL

Preservative tests, made at two Wisconsin mills, involved approximately 2,900 and 4,300 pounds of ground-wood pulp. In both cases the preservative was sprayed on the pulp on the wet machine. The results of the tests are recorded in Table 13.

Test A.—At one of the mills 18 preservatives that had appeared promising in earlier laboratory tests were used in varying concentrations with the object of checking them under mill conditions. Several of the substances were further diluted in order to determine the minimum quantity effective under commercial conditions.

The treating solutions flowed from a barrel set on a platform about 4 feet 6 inches above the suction box on the wet machine. The barrel was connected to a pipe which was perforated with holes three-sixty-fourths inch in diameter and one-half inch apart from center to center, the pipe extending along the stretch roll 2 inches above it. All pipes were copper. A strip of cloth 5 inches wide hung from the perforated pipe and brushed against the pulp. The perforations were turned upward about 45° from the horizontal, thus causing the chemical always to flow to the pulp by way of the cloth.

After treatment the commercial laps were piled in a moist basement under the wet-machine room and surrounded by the regular stock. (See Pl. XIII, fig. 2.) In computing the amount of chemical applied it is assumed that 70 per cent was retained in the pulp as it came from the wet machine. From 25 to 60 pounds of pulp, oven-dry weight, were treated with each concentration of preservative.

Test B.—This test at the second mill included five of the most promising preservatives: Boric acid, sodium borate (borax), sodium dichromate, sodium dinitrophenolate, and sodium fluoride. The solutions were made up in cold water, with the exception of borax and boric acid, which go into solution much more quickly in warm water.

The solutions, strained through fine wire mesh, were added to the pulp at the top press roll by dripping from a three-eighth-inch brass pipe perforated with one sixty-fourth-inch holes spaced three-fourths inch apart from center to center. This pipe extended the full width of the machine, and was connected with a clean 50-gallon barrel. There were two globe valves in the line for regulation of flow. The barrel was hung from the ceiling, so that the solution had a minimum head of 2 feet. It was slightly tilted to one side, and a clean-out hole provided. The rate of flow of the solution was adjusted as closely as possible by preliminary trials with the intention of setting the second valve at a fixed point and moving only the first, as a cut-off. In actual practice, however, it was found necessary to regulate the second valve from time to time, according to flow judged by the eye. The tendency of the small holes in the pipe to plug was not particularly marked, and could be compensated for by slight adjustments and by occasional picking out. With entirely clear, carefully strained solutions probably no difficulty would be experienced.

From 125 to 250 pounds of pulp, oven-dry weight, were treated with each concentration of preservative. The amount of chemical applied was figured on the basis of 70 per cent retention. After treatment, the pulp, together with a quantity of untreated material, was piled in the basement of the mill for later observation.

RETENTION OF CHEMICAL ON WET MACHINE

The amount of chemical actually retained by pulp sprayed at the press rolls depends mainly on the pressure applied at the rolls. To obtain experimental data on this question several tests involving somewhat more than 200 pounds of wet pulp were conducted on the small wet machine at the laboratory. Sodium chloride (common salt) was the chemical used, for the reason that it can very easily be washed from pulp and quantitatively determined with silver nitrate.

The salt solution was dropped on the pulp at the press roll from a three-eighth-inch brass spray pipe having one sixty-fourth-inch perforations spaced three-fourths inch between centers. The speed of the sheet was 41.9 feet per minute. Every tenth lap, or approximately one lap every five minutes, was sampled for sodium chloride and moisture.

In the case of a 5 per cent solution, approximately 70 per cent of the dry weight of salt was retained by the pulp. With a 25 per cent solution, the retention was somewhat greater (74 per cent), as less of the solution had to be applied to leave equivalent quantities of dry salt in the pulp. In mill practice some of the chemical can be recovered by recirculation of the white water.

DIFFUSION OF CHEMICAL IN PULP

The rate and amount of diffusion of chemical in the pulp have an important bearing on the tests conducted and are of particular importance in determining the commercial method of applying preservatives on the wet machine. To get information on this point, a series of special tests with sodium chloride was begun.

Some of the ground-wood laps used in the sodium chloride retention tests were reserved for the purpose, and a number of fresh laps of ground wood were run off at a moisture content of 71 to 73 per cent.

In one set of tests 14 treated and 90 untreated laps were sprayed with filtered lake water in quantities as nearly as possible equal to those used in the regular preservative tests. The treated laps were gathered into 2 bundles of 7 and folded once; the untreated into 18 bundles of 5 and folded once, making 10 thicknesses to a bundle. A "sandwich" stack was then built up of 6 untreated bundles and 1 treated bundle alternately, 5 layers in all, each layer of treated pulp thus being faced with 60 thicknesses of untreated.

In a second set of tests, 28 treated and 50 untreated laps were taken. Their moisture contents ranged from 71 to 73 per cent, and it was decided not to add water. They were folded in the same sized bundles as the laps used in the first test and piled together, the treated bundles being laid between 20-fold thicknesses of untreated laps.

Quantitative analyses of laps from the first set were made after two weeks and again after two months. The treated pulp at the beginning of the experiment contained 1.16 pounds of salt per 100 pounds of wet pulp. At the end of two weeks salt from the uppermost treated bundle, after an upward penetration of 20 thicknesses, showed a concentration of 0.04 pound per 100 pounds of wet pulp; from the lowest treated bundle, downward diffusion had evidently reached the bottom (through 60 thicknesses), where a concentration of 0.01 pound per 100 pounds was indicated.

In two months the upward diffusion from the first treated bundle exceeded 33 laps, concentration reaching 0.03 pound per 100 pounds in the thirty-third. In the sixth lap from the bottom of the pile the concentration was 0.08 pound per 100 pounds.

In the drier pulp of the second test set, observations showed that diffusion was going on with a rapidity about equal to that in the first. No formal record was kept.

During the storage phase of the preservative experiments at the Forest Products Laboratory, diffusion undoubtedly accounted for a certain amount of mingling of chemicals as well as loss by penetration into untreated spacer laps, and the lower the laps were in the pile the greater the diffusion, owing to the greater pressure and closer contact of the bundles or layers. In the second mill test, however, diffusion did not affect the results, since pulps of different treatment were placed in separate piles.

As a matter of preservation, the rapid diffusion of a chemical through pulp is highly beneficial. From the facts observed it seems perfectly safe to conclude that any minor irregularity in the application of the antiseptic is quickly compensated for, and that uniformity of treatment is insured. Under manufacturing conditions in which every lap in the pile would be treated, loss from diffusion would not occur; and, therefore, smaller amounts of chemical than were found effective in the laboratory tests can be recommended for commercial practice.

RESULTS OF PRESERVATIVE TREATMENTS

Table 13 presents a record of preservative treatments applied both at the laboratory and at the mills. In its interpretation the footnotes will help to explain certain apparent discrepancies. The results of the mill tests, which followed commercial methods, must be the final check on the value of the antiseptic.

In each series of tests a number of untreated laps were interspersed in the piles to serve as checks. Their condition was noted at different inspections. Except in a few cases where the laps dried too much, the records indicate that these check laps were severely or completely molded and decayed at the time of the last inspection.

FIG. 1.—Humidity-controlled and temperature-controlled storage shed at the Forest Products Laboratory in which ground-wood and sulphite pulps sprayed with 106 different chemicals were kept under observation for nearly two years. The laps in the background are in bundles of three, each being inoculated with five different wood-destroying fungi. The experimental pulp on the left side of the shed was inoculated with a large number of molds. The large laps are rotten hydraulic-pressed ground wood used to increase the infection. Between these are single layers of bundles, each bundle consisting of seven test laps folded once

FIG. 2.—Pile of commercial ground-wood laps treated at a Wisconsin mill with 18 different preservatives and placed in a warm, moist basement. This experimental pulp was piled at one side against the wall and was surrounded on all other sides by the regular-run ground wood

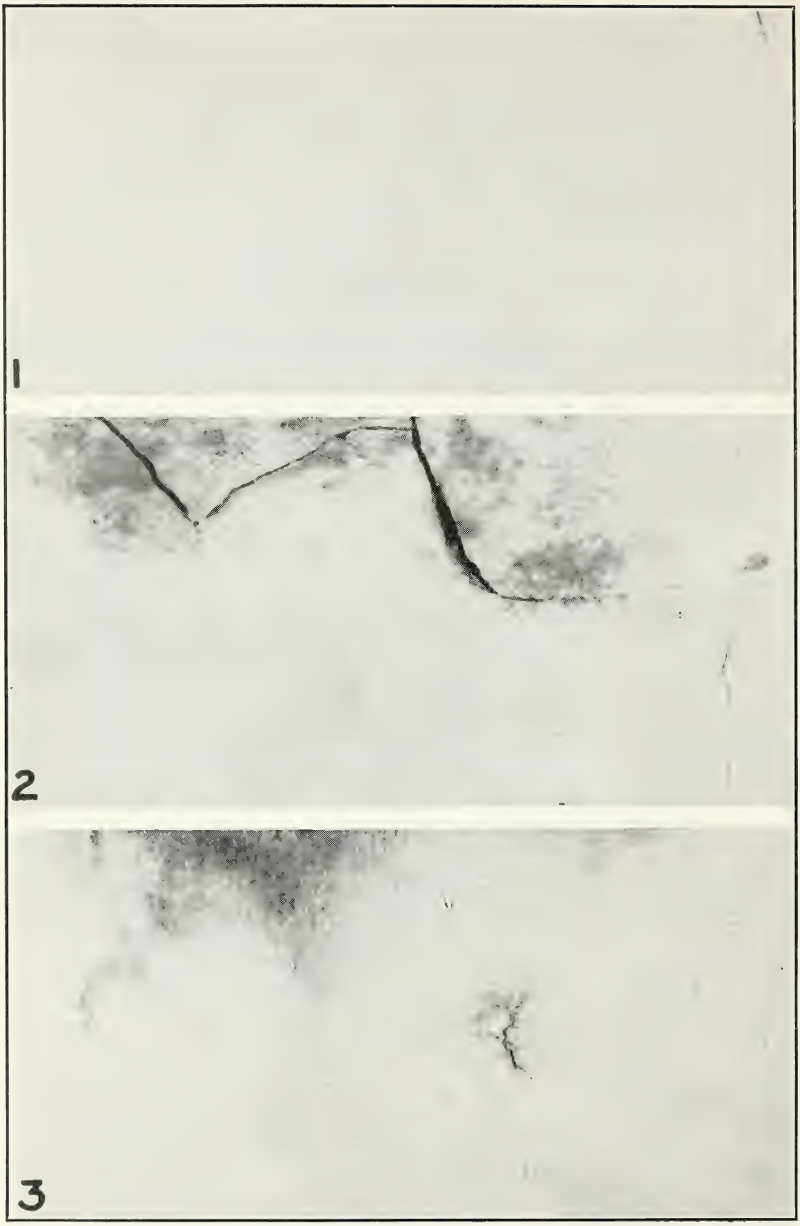

FIG. 1.—Ground-wood pulp sprayed at the Forest Products Laboratory with a 5 per cent solution of borax, inoculated, and stored for a little longer than 14 months. The sample contained approximately 1 pound of dry chemical per 100 pounds wet pulp. It is free from mold and decay

FIG. 2.—Ground-wood pulp sprayed with 0.5 per cent solution of sodium dichromate at the rate of approximately 0.1 pound dry salt per 100 pounds wet pulp. This amount of chemical did not prevent serious decay and molding after 14 months' storage, as shown

FIG. 3.—Ground-wood pulp sprayed with a concentrated solution of sulphite liquor at the rate of 14.7 pounds of solution per 100 pounds wet pulp. After 13½ months' storage the pulp was very badly molded and decayed

TABLE 13.—*Preservative treatment of pulps*

["A" or "B" appearing in the second column refers to test A or test B described in the text. "S" denotes sulphite pulp. All other was ground wood]

Preservative[1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Alphanaphtylamine[2]	5.7	Yellow	11	Molded and very rotten.
Do[2]	9.3	do	11	Severely molded and decayed.
Do[2]	10.1 S		11	Considerably molded and decayed.
Do[2]	21.9 S	Slightly brown	11	Somewhat molded and decayed.
Aluminum chloride, c. p.	39.9	None	12	Severely molded and decayed.
Aluminum sulphate, c. p.	88.0	do	12	Do.
Aluminum and potassium sulphate, c. p.	96.9	do	12	Do.
Ammonium bifluoride	10.9	Bleaches	11	Do.
Do	28.9	do	11	Do.
Do	22.9 S	do	11	Do.
Do	46.2 S	Slightly brown	11	Somewhat molded and decayed.
Ammonium carbonate, c. p.	81.4	None	12	Severely molded and decayed.
Ammonium chloride	97.6	do	12	Do.
Ammonium fluoride	14.7		11	Do.
Do	35.4		11	Do.
Do	68.5	Brittle	11	Considerably molded.
Do	14.7 S	Soft	11	Severely decayed.
Do	23.8 S	do	11	Severely molded and decayed.
Do	56.1 S	Slightly brown	11	Severely decayed.
Ammonium nitrate	103.4	None	12	Severely molded and decayed.
Ammonium sulphate	57.5	do	11	Do.
Barium chloride, c. p.	53.2	do	13	Do.
Do	86.5	do	13	Do.
Do	94.8	Slightly brown	12	Slightly molded and decayed. Fair condition at 24 months.
Beta naphthol	1.0	None	13	Severely molded and decayed.
Do	5.7 S	Purple-brown	24	Slightly molded; no decay.
Boric acid[2]	24.7 B		7	Good condition; slightly molded.
Do[2]	82.2	Pink-brown	13	Slightly molded. Failed before 24 months.
Do[2]	126.7 S	Slightly brown	24	Slightly molded.
Borobenzoic acid[2 3]	34.3	None	11	Severely molded and decayed.
Do[2 3]	63.0 S	Slightly brown	11	Slightly molded. Somewhat worse at 22 months.
Monobromo naphthalene[3]	5.3	None	12	Severely molded and decayed.
Do[3]	9.4	do	12	Do.
Do[4]	9.6 S	Slightly brown	12	Somewhat molded; no decay. No change at 24 months.
Calcium benzoate	10.9	None	11	Severely molded and decayed.
Do[2]	25.2	do	11	Do.
Do[2]	55.4	do	11	Do.
Do[2]	23.3 S	do	11	Do.
Do[2]	49.8 S	do	11	Do.
Do[2]	95.3 S	do	11	Do.
Calcium borate	57.9	do	11	Do.
Do	132.8 S	do	11	Do.
Calcium chlorate	61.2	Yellowish	11	Do.
Do	110.2 S	None	11	Somewhat molded and decayed.
Calcium chloride	86.8	do	12	Severely molded and decayed.
Calcium sulphocarbolate	35.4	do	11	Do.
Do	95.6 S	do	11	No mold or decay. Slightly molded and apparently somewhat decayed at 22 months.
Carbolic acid	19.9	do	13	Somewhat molded; no decay. Failed before 24 months.
Carvacrol oil No. 5[5, 6]	37.0 A	do	16	No mold or decay.
Carvacrol oil No. 4[7, 6]	37.0 A	Slightly pink	16	Very slightly molded.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative [1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Carvacrol oil No. 1 [8, 6]	37.0 A	None	16	Slightly molded and decayed.
Do	912.0	Brown	24	Slightly molded; no decay.
Do.[4]	269.0 S	Slightly brown	24	No mold or decay.
Do.[4]	463.0 S	do	24	Do.
Chromium sulphate	96.3	Bluish	13	Severely molded; slightly decayed.
Do	95.1 A	Slightly green	6	Severely molded.
Copper acetate	9.7	None	13	Severely molded and decayed.
Do	18.5 A	Slightly brown	6	Somewhat molded and decayed. Failed before 16 months.
Do	18.7	do	13	Somewhat molded and decayed.
Do	27.8 A		6	Somewhat molded at 6 months; considerably at 16 months.
Do	37.1	Brown	13	Somewhat molded; no decay. No change at 24 months.
Do	45.4	do	24	Slightly molded; no decay.
Do	9.7 S	Slightly brown	12	Slightly molded and decayed.
Do	20.0 S	do	12	Somewhat molded; no decay.
Do	41.0 S	Brown	12	Somewhat molded and decayed.
Do	65.9 S	do	12	Do.
Copper bromide	29.7	Slightly brown	12	Severely molded and decayed.
Copper chloride	17.7	do	13	Severely molded.
Do	57.4	do	13	Severely molded and decayed.
Do	89.7	do	13	Severely molded; no decay.
Do	100.3 S	Brown	12	Somewhat molded; no decay. Somewhat decayed at 24 months.
Copper fluoride	7.4	Slightly brown	11	Severely molded and decayed.
Do	10.1 S	do	11	Slightly molded; no decay. Severely molded at 22 months.
Copper nitrate, c. p	40.6	do	13	Severely molded and decayed.
Do	60.9	do	13	Do.
Do	64.1 S	do	12	Do.
Copper sulphate	77.9	Brown	13	Severely molded; slightly decayed.
Do	119.7 S	do	12	Somewhat molded and decayed. Failed before 24 months.
Cymene (crude)	2.0	None	10	Severely molded.
Do	160.0	do	6	Somewhat molded.
Cymene and naphthalene [9] (equal parts by weight).	1.0	do	10	Do.
Do.[9]	2.0	do	10	Slightly molded.
Do.[9]	4.0	do	10	No mold or decay.
Dichlorobenzene	2.0	do	6	Slightly molded.
Do	4.0	do	6	Very slightly molded on outside.
Do	32.0	do	6	No mold or decay.
Do	48.0	do	6	Do.
Do	80.0	do	6	Slight mold on outside.
Ferric chloride, U. S. P	37.9	Brown	13	Severely molded and decayed.
Ferric nitrate	92.7	Darkened	12	Do.
Ferric sulphate, c. p	116.3	do	12	Do.
Paraformaldehyde [3]	32.1	None	11	Do.
Do.[3]	72.9	do	11	Somewhat molded and decayed.
Do.[3]	50.9 S	do	11	Slightly molded; no appreciable decay. Considerably molded and decayed at 22 months.
Do.[3]	113.0 S	do	11	Severely molded and decayed.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative[1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Hydrosilicofluoric acid[10]	44.9	Brown	13	Somewhat molded; slightly decayed.
Do.	95.3		13	Severely molded and decayed.
Lactic acid, U. S. P.	61.1	Slightly brown	12	Do.
Lead acetate	45.0	None	13	Slightly molded and decayed. No change at 24 months.
Do.	46.1 A	do	6	Severely molded; slightly decayed.
Do.[11]	69.4 A	do	16	Severely molded; very slightly decayed.
Do.	76.5	do	13	Severely molded and decayed.
Do.	45.3 S	do	12	Do.
Do.[12]	123.5 S		12	Do.
Lead nitrate	90.3	Slightly brown	12	Do.
Do.	99.0 S	Pinkish	12	Somewhat molded. Slightly decayed at 24 months.
Lysol	96.4	None	13	Considerably molded; no decay. No change at 24 months.
Magnesium ammonium chloride.	102.3	Slightly brown	12	Severely molded and decayed.
Magnesium chloride	24.9	None	13	Do.
Do.	95.1 A	do	16	Do.
Magnesium nitrate, c. p.	87.6	do	12	Do.
Magnesium silicofluoride[12]	34.1	do	11	Severely molded; no appreciable decay. No change at 22 months.
Do.	52.7		11	Somewhat molded.
Do.	57.9 S	None	11	Considerably molded and decayed.
Do.	111.1 S	do	11	Do.
Magnesium sulphate	87.2	do	12	Severely molded and decayed.
Manganese sulphate	90.2	do	12	Do.
Mercuric acetate[13]	8.1	Slightly brown	11	Somewhat molded and decayed.
Do.	10.6	do	11	Do.
Do.	11.0 S		11	Do.
Do.	21.8 S		11	Do.
Nickel sulphate	36.2		12	Severely molded and decayed.
Mononitrobenzene[14]	6.4	None	12	Do.
Do.[3]	7.0	do	12	Do.
Do.[15]	9.2 A	do	6	Severely molded; somewhat decayed.
Do.[15]	13.1 A	do	6	Somewhat molded and decayed.
Do.[14]	7.5 S	do	12	Somewhat molded; no decay. No change at 24 months.
Dinitrochlorobenzene	3.5	do	11	Somewhat molded and decayed.
Do.	6.2	Slightly brown	11	Slightly molded. Considerably decayed at 22 months.
Do.	10.0	Brown	11	No mold or decay. Somewhat molded and decayed at 22 months.
Do.	5.8 S	Slightly brown	11	Do.
Do.	9.9 S	do	11	No mold or decay. Slightly molded at 22 months.
Do.	20.3 S	do	11	No mold or decay. Somewhat molded and decayed at 22 months.
Orthonitrophenol[14]	2.1	Slightly yellow	12	Severely molded and decayed.
Do.[3]	2.4		12	Do.
Do.[14]	4.2		12	Do.
Do.[3]	4.3	Yellow	12	Do.
Do.[14]	7.0	Slightly brown	12	Do.
Do.[3]	8.7		12	Do.
Do.[14]	6.8 S	Darkened	12	Somewhat molded and decayed.
Do.[14]	9.4 S		12	Considerably molded and decayed.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative [1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Paranitrophenol [9]	2.0	None	6	Severely molded and decayed.
Do. [9]	4.0	do	6	Somewhat molded and decayed.
Dinitrophenol [9]	2.0	Slightly yellow	6	Considerably molded.
Do. [9]	4.0	Somewhat yellow	6	Slightly molded.
Mononitrotoluene	1.0	Slightly brown	6	Severely molded.
Do	2.0	do	6	Do.
Do	4.0	do	6	Somewhat molded.
Do. [3]	7.2	None	12	Severely molded and decayed.
Do	8.0	Slightly brown	6	Somewhat molded.
Do. [14]	10.4	None	12	Severely molded and decayed.
Do. [14]	8.4 S	do	12	Somewhat molded; no decay. No change at 24 months.
Orthonitrotoluene [15]	4.6 A		6	Somewhat molded and decayed.
Do. [15]	7.0 A	do	6	Do.
Do. [15]	13.8 A	do	16	No appreciable mold or decay.
Dinitrotoluene [14]	7.1	Slightly yellow	12	Somewhat molded; severely decayed.
Do. [3]	8.6	do	12	Severely molded and decayed.
Do. [14]	8.2 S		12	Somewhat molded and decayed.
Oxalic acid	41.9	None	13	Severely molded and decayed.
Do	79.0	Pinkish	13	Do.
Do	50.1 S	None	12	Somewhat molded and decayed.
Do	83.8 S	Purplish	12	Somewhat molded; slightly decayed. No change at 24 months.
Potassium bromate	91.5	None	13	Somewhat molded; no decay. No change at 24 months.
Potassium chlorate	52.6	Brown stains	12	Severely molded and decayed.
Do	113.0	do	12	Do.
Do	44.9 S	None	12	Somewhat molded. Also somewhat decayed at 24 months.
Do	94.4 S	do	12	Severely molded; somewhat decayed.
Potassium permanganate	7.0	Dark brown	13	Severely molded and decayed.
Do	10.0	do	13	Do.
Do	15.2	do	13	Do.
Do	11.4 S	Brown	12	Somewhat molded and decayed.
Do	14.7 S	do	12	Somewhat molded, severly decayed.
Potassium silicofluoride	11.2	None	11	Severely molded and decayed.
Do	20.2 S	do	11	Do.
Quebracho extract	104.5	Brown	13	Somewhat decayed. Failed before 24 months.
Do	202.4	do	13	Somewhat molded. Failed before 24 months.
Salol [16]	6.9	None	11	Severely molded and decayed.
Do. [2]	17.9	do	11	Do.
Do. [16]	13.4 S	do	11	Do.
Do. [2,16]	13.8 S	do	11	Do.
Do. [2]	26.9 S	do	11	Do.
Sodium acetate	89.8	do	12	Do.
Do	102.6 S	Brown stains	12	Severely molded; no decay. No change at 24 months.
Sodium aluminate	82.1	Slightly brown	11	Severely molded and decayed.
Do	118.1 S	do	11	Somewhat molded and decayed.
Sodium arsenate, c. p	43.0	None	24	Slightly molded; no decay.
Do	97.8	do	24	Do.
Do	56.7 S	Slightly brown	24	Do.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative[1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Sodium arsenate, c. p	107.9 S	Slightly brown	12	Very slightly molded; no decay. No change at 24 months.
Sodium arsenite, c. p	102.8	None	24	Slightly molded; no decay.
Do	94.6 S	do	12	Considerably molded; no decay. No change at 24 months.
Sodium benzoate	15.3	do	11	Severely molded and decayed.
Do	41.4	do	11	Do.
Do	70.5	do	11	Do.
Do	19.2 S	do	11	Do.
Do	52.4 S	Slightly brown	11	Do.
Do	100.2 S	do	11	Severely molded; somewhat decayed.
Sodium bicarbonate	109.3	Brown	12	Severely molded and decayed.
Do	203.1	do	24	Slightly molded; no decay.
Do	106.2 S	Slightly brown	24	Do.
Do	188.1 S	Brown	24	No mold or decay.
Sodium borate (borax)	54.1 B		7	Severely molded; no decay.
Do	83.7 A	Slightly brown	6	Considerably molded; no decay. No change at 16 months.
Do	90.0	do	24	Slightly molded; no decay.
Do.[2]	130.2 A	do	16	Do.
Do.[2]	135.9	do	13	Slightly molded and decayed. No change at 24 months.
Do.[2]	99.0 S	do	12	Slightly molded and decayed.
Sodium bromate, c. p	81.6		12	Severely molded and decayed.
Do	125.7 S	Slightly brown	11	Do.
Sodium carbonate	124.8	Brown	13	Slightly molded; no decay.
Do	173.3	do	13	Somewhat molded; no decay. No change at 24 months.
Do	125.5 S	Slightly brown	24	Slightly molded; no decay.
Do	204.1 S	Brown	12	Somewhat molded; slightly decayed. No change at 24 months.
Sodium chloride (salt)	174.6	None	12	Severely molded and decayed.
Sodium citrate	83.5	Slightly brown	13	Considerably molded and decayed.
Sodium cyanide	91.3	Brown	12	Severely molded and decayed.
Do	106.5	do	12	Do.
Sodium dichromate	4.0	None	6	Very slight molding.
Do	7.9 B		7	No mold or decay.
Do	8.0	Slightly darkened	6	Very slight molding.
Do	10.6	None	13	Severely molded and decayed.
Do	13.8 A	Slightly yellow	16	Very slightly molded; no decay.
Do	16.0	Slightly darkened	6	No mold or decay.
Do	20.6	None	13	Severely molded and decayed.
Do	27.8 A	Slightly yellow	16	Slightly molded; no decay.
Do	32.0	Slightly darkened	6	No mold or decay.
Do	33.5	Slightly yellow	13	Somewhat molded and decayed.
Do	20.9 S	None	24	Slightly molded; no decay.
Do	41.3 S	Yellow stains	12	Somewhat molded; slightly decayed.
Sodium fluoride	8.0	None	6	Slightly molded.
Do	16.0	do	6	Do.
Do	18.5 A	do	6	Considerably molded; no decay. No change at 16 months.
Do	21.9 B	do	7	Slightly molded; no decay.
Do	27.8 A	do	6	Considerably molded; no decay. No change at 16 months.
Do	32.0	do	6	Very slightly molded.

See footnotes on page 43.

TABLE 13.—*Preservative treatment of pulps*—Continued

Preservative [1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Sodium fluoride	37.2 A	None	6	Slightly molded; no decay. No change at 16 months.
Do	48.0	do	6	No mold or decay.
Do	54.7	do	12	Slightly molded; no decay. Slightly decayed at 24 months.
Do	86.7	do	12	Severely molded and decayed.
Do	57.1 S	do	24	No mold or decay.
Do	86.0 S	do	24	Slightly molded; no decay.
Sodium nitrate	77.4	do	12	Severely molded and decayed.
Sodium paranitrophenolate	1.1	do	13	Do.
Do	2.0	Deep yellow	13	Do.
Do	3.2	do	13	Do.
Do	10.2	do	13	Do.
Do	13.8	do	13	Do.
Do	1.5 S	Slightly yellow	12	Do.
Do	2.6 S		12	Do.
Do	5.7 S		12	Somewhat molded and decayed.
Do	9.8 S		12	Severely molded and decayed.
Do	22.7 S		12	Somewhat molded and decayed.
Sodium dinitrophenolate	1.1 B	Slightly yellow	7	Very slightly molded.
Do	1.2 A	do	16	Somewhat molded; no decay.
Do	1.3	do	13	Slightly molded; no decay. Slightly decayed at 24 months.
Do	1.5 A	do	16	Somewhat molded; no decay.
Do	1.9 A	do	16	Somewhat molded and decayed.
Do	2.1 B	Yellow	7	Somewhat molded; no decay.
Do	2.1	do	13	Somewhat molded; no decay. No change at 24 months.
Do	4.6	do	13	Somewhat molded and decayed.
Do	6.5	Deep yellow	13	Slightly molded and decayed. No change at 24 months.
Do	10.8	do	24	Slightly molded; no decay.
Do	1.3 S		12	Somewhat molded; considerably decayed.
Do	2.9 S	Slightly yellow	12	No appreciable mold or decay. Slightly molded and decayed at 24 months.
Do	6.7 S	Yellow	24	No appreciable mold or decay.
Do	9.8 S	do	12	Somewhat molded; no decay. No change at 24 months.
Do	21.3 S	Deep yellow	12	No mold or decay. Very slightly molded at 24 months.
Sodium phosphate, monobasic	82.8	None	12	Severely molded and decayed.
Do	80.0	do	6	No mold or decay.
odium phosphate, dibasic, c. p.	48.0	do	6	Somewhat molded.
Do	80.0	do	6	Do.
Do	95.1 A		6	No mold or decay. Considerably molded at 16 months.
Sodium phosphate, tribasic	48.0	None	6	Slightly molded and decayed.
Do	80.0	do	6	Slightly molded.
Soduim salicylate	53.7	Very dark	12	Severely molded and decayed.
Do	79.8	do	12	Do.
Do	49.2 S	Slightly brown	12	Severely molded; no decay.
Do	96.4 S		12	Do.
Sodium silicofluoride	34.1	None	11	Slightly molded and decayed. No change at 24 months.
Do	59.2 S	do	11	Do.
Sodium sulphite, c. p.	157.7	Slightly brown	12	Severely molded; considerably decayed.

See footnotes on page 43.

TABLE 13.—*Preservative treatment oj pulps*—Continued

Preservative [1]	Pounds of chemical per ton oven-dry pulp	Effect of chemical on pulp	Months in storage	Condition at time of inspection
Sodium sulphocarbolate	56.4	None	11	Severely molded and decayed.
Do	114.1 S	do	11	Considerably molded and decayed.
Sodium and potassium tartrate, c. p.	75.4	Slightly brown	12	Severely molded and decayed.
Sodium thiosulphate (hypo)	218.5	None	12	Do.
Sumach extract	192.4	Brown	12	Do.
Thymol	0.2	None	13	Do.
Do	0.4	do	13	Considerably molded and decayed.
Do	0.9 A	do	6	Slightly molded and decayed. No change at 16 months.
Do	0.9	do	13	Considerably molded and decayed.
Do	1.9 A	do	6	Slightly molded and decayed. Somewhat worse at 16 months.
Thymol oil No. 2 [6, 17]	18.5 A	do	16	Slightly molded; no decay.
Do. [6, 17]	37.0 A	do	16	No mold or decay.
Thymol oil No. 3 [6, 18]	37.0 A	do	16	Very slightly molded.
Thymol	0.9 S	do	12	Severely molded; somewhat decayed.
Zinc chloride	108.6	Darkened	12	Severely molded; no decay. No change at 24 months.
Do	105.8 S		12	Severely molded; somewhat decayed.
Zinc silicofluoride	32.9	None	11	Somewhat molded; no decay. No change at 22 months.
Do	57.7	do	11	Somewhat molded; no decay. Somewhat decayed at 22 months.
Do	80.0	do	6	Slightly molded.
Do	53.5 S	do	11	Slightly molded; no decay. Slightly decayed at 22 months.
Do	104.5 S	do	11	Slightly molded; considerably decayed. No change at 22 months.
Zinc sulphate, c. p.	95.7	Slightly brown	13	Severely molded; no decay.
Zinc sulphocarbolate	57.4	None	11	Severely molded; considerably decayed.
Do	106.2 S	do	11	No appreciable mold or decay. Slightly molded and decayed at 22 months.

[1] Unless otherwise indicated, the chemicals were of "technical" quality.
[2] Solutions applied warm or hot.
[3] Saturated solution with some chemical in suspension.
[4] Diluted with 95 per cent alcohol.
[5] Volatile oil of *Monarda fistulosa*, yielding carvacrol. Prepared and donated by the department of chemistry, University of Wisconsin (oil No. 5).
[6] The emulsions of oils No. 1, 2, 3, 4, and 5 were made in the following manner, using rosin size of about the same concentration as in 15. The rosin size was not cleared by use of excess sodium hydroxide. The oils added in small amounts were shaken with an equal volume of the emulsifying agent, then diluted to 15,000 c. c. with water. The amounts of oil and emulsifying agent used were: No. 1 with equal volume of rosin size, slightly alkaline. No. 2 with equal volume of rosin size, plus 0.1 volume of saponin solution. No. 3 with equal volume of rosin size, plus 0.4 volume of saponin solution. No. 4 with equal volume of rosin size. No. 5 with equal volume of rosin size, plus 0.1 volume of saponin solution.
[7] Phenol portion of 5 (oil No. 4).
[8] Nonphenol portion of 5 (oil No. 1).
[9] The undissolved portion of solid chemical was put on surface of pulp.
[10] This chemical appears to attack the fiber and weaken the pulp. It gives a pinkish cast to the pulp.
[11] Solution made up in zinc-lined vessel, and lead precipitated out.
[12] Appears to weaken the pulp.
[13] On exposure to air and light solution forms red mercuric oxide.
[14] Strong solution made up in 95 per cent alcohol and diluted to the desired concentration with water.
[15] The emulsions of nitrobenzene and orthonitrotoluene were made by shaking with the oils an equal volume of rosin size, of about the same concentration used in the paper mill, which had been previously cleared by adding NaOH solution. The oils were added in small amounts to the size solution and well shaken before adding the next portion. This gives an emulsion with the oils as the discontinuous phase and water as the continuous phase.
[16] First sprayed with salol, then with 0.5 per cent sodium carbonate.
[17] Volatile oil of *Monarda punctata*, yielding thymol. Prepared and donated by the department of chemistry, University of Wisconsin (oil No. 2).
[18] Nonphenol portion of 17 (oil No. 3).

REQUIREMENTS A PRESERVATIVE MUST MEET TO BE SUITABLE

In the selection of a preservative, several characteristics besides effectiveness as an antiseptic must be given consideration, such as:

1. Poisonous properties.
2. Chemical discoloration produced in the pulp.
3. Odor.
4. Solubility in cold water.
5. In the case of oils, ease of emulsification.
6. Cheapness and availability.

Some substances which are quite efficient as antiseptics must necessarily be ruled out of commercial use, because in the handling of either the solutions or the sprayed pulp sufficient quantities of the poison might be absorbed through the skin to impair the health of the worker. Likewise, violent poisons which might accidentally enter the body through the mouth must be avoided in order to protect the consumer. Examples of such dangerous substances are mercuric chloride (corrosive sublimate), sodium arsenate, and sodium cyanide.

Some highly efficient antiseptics produce objectionable discolorations in the treated pulp, which are due either to the color of the chemical or to caustic or other action on the wood fiber. All of the alkalies produce browning, the depth of which depends on the substance used and the concentration of the solution employed. For instance, borax produces a slight browning which is not objectionable, whereas both sodium carbonate and sodium bicarbonate will so distinctly darken the pulp as to make it unfit for commercial use unless it is to be bleached later. Sodium dichromate, likewise, ultimately browns the pulp to a considerable degree if applied at a rate of 20 pounds or more per ton. At some mills there might be objection to this darkening, but at the mill where the tests were made there seemed to be no objection to it. Sodium dinitrophenolate is apparently not adapted to commercial use on ground wood in amounts larger than 2 pounds per ton. Even at 0.9 pound per ton the yellow tint produced, though it readily leaves the pulp on washing, is distinctly noticeable.

None of the substances recommended hereafter give rise to objectionable odors, but the opposite is true of some of the chemicals experimented with.

Solubility in cold water is a very important property, as in most cases the chemicals are most easily applied in the form of water solutions.

Oils are preferably to be emulsified in order to secure the proper dilution. The readiness with which they emulsify is an important factor in their application.

Of course, price and availability will have much to do with the selection of the chemical to use. The results from the treatment must justify the cost of it. How much the treatment will cost depends largely on how much of the chemical is necessary to treat a unit of pulp effectively.

CHEMICALS GIVING MOST FAVORABLE RESULTS

Of the chemicals tried, six gave favorable results in preventing mold and decay and also met other requirements sufficiently well to warrant their commercial consideration. Brief information concerning these follows.

Borax is a white substance, 5.3 per cent soluble in water at 70° F. and 7.4 per cent at 86° F. It is nonpoisonous and therefore safe for workmen to handle. It slightly darkens the pulp but not to an objectionable degree. About 17 pounds of ground wood and 5 pounds of sulphite were treated with borax at the laboratory; 450 pounds of ground wood were treated at the mills. The borax treatments at the laboratory held the pulp in good condition (with slight molding in a few cases) for six to eight months. Tests lasting for from 13 to 24 months gave quite satisfactory results. (See Pl. XIV, fig. 1.) The mill tests, with 54 to 84 pounds of chemical per ton dripped on the pulp back of the press rolls, were not so favorable, the pulp having molded considerably within six months.

Boric acid is 4.8 per cent soluble in water at 68° F. and is colorless in solution. It is nonpoisonous and safe to use, but more expensive than borax. It gives a slight pinkish-brown color to ground wood. About 10 pounds of ground wood and 4 pounds of sulphite were treated with boric acid at the laboratory; 160 pounds of ground wood were treated at the mill. After six months, the pulp was somewhat molded but in fairly good condition. After 12 to 13 months it was still in fair condition, with no active decay present.

Cymene-naphthalene mixture.—Spruce turpentine (crude cymene) is a reddish-brown liquid by-product of the sulphite mill. Naphthalene is the white substance used commonly as moth balls. It is 33⅓ per cent soluble in cymene at 122° F.

Pulp treated with naphthalene alone remained in good condition directly under the crystals, but became badly molded elsewhere. (Pl. XV, fig. 1.) With cymene alone, severe molding occurred. (Pl. XV, fig. 2.) About 150 pounds of ground-wood pulp were treated with mixtures of equal parts by weight of the two substances. Four pounds per ton of this mixture preserved the pulp perfectly for 10 months. The writers advise the use of 1½ pounds of naphthalene dissolved in 6 pounds of cymene to a ton of dry pulp. To facilitate uniform application, the chemicals should be emulsified with the aid of rosin soap and diluted with water. (Pl. XV, figs. 3 and 4.)

Sodium fluoride is a white salt 4.3 per cent soluble in water at 64° F. It is perfectly safe for workmen to handle and causes no chemical discoloration of the pulp. At the laboratory about 11 pounds each of ground wood and sulphite were treated with sodium fluoride; at the mills 735 pounds of ground wood were so treated. The mill application of 18 to 28 pounds of chemical per ton gave somewhat variable results up to 16 months, the pulp in some cases being only slightly blue-black molded and in others rather badly so. It was, however, free from decay. Thirty-seven pounds per ton preserved the pulp very well, permitting only slight molding after 16 months. Part of the pulp at the mill was somewhat molded after six months, but not seriously.

Sodium dinitrophenolate is a yellow salt producing a yellow solution. It is approximately 2.4 per cent soluble in water at 59° F. Although in its concentrated form it is considered an industrial poison, it is thought that in the dilution hereinafter recommended it will not injure the health of workmen, provided reasonable care be exercised. In the lower concentrations it colors the pulp slightly yellow, and in the higher distinctly so. This color readily washes out, but the washed pulp may be left somewhat darker than normal. About 14 pounds of ground wood and 22 pounds of sulphite were treated with sodium dinitrophenolate at the laboratory; 430 pounds of ground wood were treated at the mill. From 1 to 2 pounds of chemical per ton preserved the pulp from decay for periods up to 16 months, but did not prevent all molding. Up to six months these concentrations proved highly efficient. On sulphite, 3 pounds per ton almost perfectly preserved the pulp for 24 months. Concentrations of 4 pounds and higher are somewhat more effective, but they color the pulp rather too yellow.

Sodium dichromate is a reddish-brown substance readily soluble in cold water, yielding an orange-yellow solution. When applied at the rate of about 30 pounds per ton it immediately stains the pulp a slight yellow, and the discoloration, on standing, becomes brownish, darkening the pulp somewhat. Although classed as a poison, sodium dichromate is not considered dangerous to handle. About 45 pounds of ground wood and 11 pounds of sulphite were treated with this preservative at the laboratory; 230 pounds of ground wood were treated at the mills. The addition of 8 pounds of chemical per ton at one mill preserved the pulp for seven months. From 14 to 28 pounds of chemical per ton at another mill permitted only slight molding in 16 months. The laboratory results were not so good. Ten pounds per ton preserved the pulp for three months but failed in six months. (Pl. XIV, fig. 2.) From 20 to 33 pounds per ton kept it in rather good condition for 6 months, but failed in 13 months. The sulphite pulp held up better than ground wood.

COMMENTS ON OTHER CHEMICALS

Beta naphthol (1 pound per ton) failed, under a severe laboratory test, to preserve ground wood for as long as 13 months, but 6 pounds per ton almost perfectly preserved sulphite pulp for 2 years. Because this substance is but slightly soluble in water, it was applied in suspension. Dusting the dry chemical on the pulp may prove a better procedure.

Copper acetate gave unfavorable results when used at the rate of 10 pounds per ton. Thirty-seven pounds per ton gave rather good results. It browns the pulp considerably.

Copper acetoarsenite (Paris green) gave efficient protection when used at a rate of 7 pounds per ton. It is too poisonous to handle, however, and gives a deep green surface discoloration to the pulp.

Copper sulphate at a rate of 78 pounds per ton gave considerable protection.

Dichlorobenzol was highly effective in the excessive amounts employed, and further tests should be made at lower concentrations. It was used in the form of a crude oil, but dilute emulsions in water probably can be easily made. It is volatile, and the odors are oppressive in a closed space but not particularly poisonous. It is used in the crystalline form as a very effective insecticide in herbaria, etc.

Dinitrochlorobenzol proved very effective when applied at the rate of 6 pounds per ton, but on account of its highly poisonous properties it can not be recommended as a pulp preservative.

Lysol (96 pounds per ton) protected the pulp from decay but permitted severe molding.

Magnesium silicofluoride (53 pounds per ton) and *zinc silicofluoride* (33 pounds per ton) gave a considerable measure of protection, but further data are needed in regard to their possible action in weakening the pulp.

Sodium arsenate (43 pounds per ton) and *sodium arsenite* (102 pounds per ton) protected the pulp to a considerable extent, but on account of their highly poisonous character can not be recommended.

Sodium bicarbonate, ordinary baking soda, browned the pulp as did sodium carbonate, and also apparently softened it.

Sodium carbonate, a white salt readily soluble in cold water, is a fairly strong alkali. It was found to brown the pulp to a marked degree. The discoloration readily bleaches out of sulphite pulp, without increased bleach consumption, but the pulp is somewhat softened by the action of the alkali.

Thymol gave considerable protection in some cases, but the results were too erratic to warrant recommendation until further and more uniformly favorable data are obtained. The mill tests (none were made at the laboratory) of the two distillates from the thymol-yielding plant *Monarda punctata* resulted very favorably. However, large quantities of these distillates are not available at present.

Mill tests of the three distillates from the carvacrol-yielding plant *Monarda fistulosa* also gave favorable results. Production of these distillates on a commercial scale would perhaps bring their cost low enough to permit their use.

Zinc chloride (108 pounds per ton) gave very favorable results in preserving the pulp against decay but permitted heavy infections of speckled gray mold.

The following preservatives, in addition to those listed in Table 13, have for various reasons proved unsatisfactory under the severe conditions imposed in the laboratory tests: Calcium hydrate, copper oleate, formaldehyde, formic acid, mercuric chloride, naphthalene (dry and in alcoholic solution), rongalite, sodium bifluoride, bleach liquor, and fresh and waste sulphite liquor. (Pl. XIV, fig. 3.)

PREVALENCE OF VARIOUS FUNGI ON TREATED PULP

The molds most commonly found on the experimental pulp, listed in the order of their frequency of occurrence, were those respectively producing neutral gray, pink, purple, and yellow spots or blotches. Neutral gray discolorations were attributable to any one of several molds that have brown mycelia. Species of Penicillium and Fusarium produced discolorations pink to purple in tint, and some species of Trichoderma caused yellow areas.

Gray discolorations were found quite generally throughout the packs. Certain molds were more frequently found on the outer laps and along the edges and folds than elsewhere. The ammonium salts, sodium chloride, and sulphite liquors seemed to stimulate all kinds of fungous growth. Pulp which had been sprayed with copper nitrate, lead acetate,[4] and zinc chloride was found covered with numerous minute gray specks.

Mercuric chloride permitted the light-colored molds, Penicillium and Trichoderma especially to develop.

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[4] When prepared in zinc-lined vessels, this salt was largely changed over to zinc acetate.

Alphanaphtylamine, aluminum fluoride, aluminum sulphate, potassium bromate, potassium permanganate, salol, sodium aluminate, and sodium sulphocarbolate seemed to check all the molds except those causing the neutral gray discolorations, but they did not control the wood-destroying fungi.

Potassium permanganate colored the pulp a dark brown, but the wood-destroying fungi bleached out this color.

PRESERVATIVES RECOMMENDED FOR MILL APPLICATION

Of the preservatives reported upon, sodium fluoride shows the highest antiseptic effectiveness and the fewest objectionable features for mill application. Cost is the main objection to it. Borax is a close second.

Boric (boracic) acid is equal or somewhat superior to borax, but its greater cost throws it out of competition.

A combination of naphthalene and cymene in the proportions recommended above, promises to be nearly as effective as sodium fluoride, and is very much cheaper.

Sodium dinitrophenolate, applied at the rate of 2 pounds per ton, appears very promising. In antiseptic efficiency it is equal to anything tried, but the yellowish chemical discoloration it causes may render the pulp objectionable for some purposes. This stain, however, readily washes out, although it may leave the pulp somewhat browner than normal.

Sodium dichromate did not seem to give quite as good results as the four substances just mentioned. Its antiseptic efficiency varied rather too widely in the tests, and its tendency toward browning of the pulp was rather marked, particularly when applied at a rate of 32 pounds per ton.

Preservative solutions should be applied at the press roll, in which case the retention is about 70 per cent for a 5 per cent solution. The loss of chemical in the white water must be compensated for in order to get the necessary actual concentration in the pulp. There is no danger of the treated pulp sticking to the rolls.

Preservative solutions can not be effectively applied to pulp in storage, either before or after infection has taken place. Any method of dipping or spraying that would be satisfactory would not be economically feasible. It thus appears a much simpler matter to prevent the development of molds and decay than to stop it.

Aside from technical difficulties in application the deciding factor in the commercial use of any chemical is its cost, and this fact has not been lost sight of in this investigation.

On the assumption that the pulp normally leaves the wet machine one-third dry, the cost of various chemicals per ton of air-dry pulp, at the market prices of July 9, 1923, would be as follows:

	Cost per ton of pulp
Borax, 80 pounds per ton, at 5¼ cents per pound	$4.20
Boric acid, 80 pounds per ton, at 10 cents per pound	8.00
Crude cymene, 6 pounds per ton, at 6¼ cents per pound, and crude naphthalene, 1½ pounds per ton, at 3 cents per pound	.42
Sodium fluoride, 48 pounds per ton, at 8¾ cents per pound	4.20
Sodium dinitrophenolate, 2 pounds per ton, at 40 cents per pound (for dinitrophenol)	.80
Sodium dichromate, 16 pounds per ton, at 8 cents per pound	1.28

In some cases the amount of chemical recommended above is less than that indicated in Table 13 as the effective quantity, but it should be borne in mind that there was a much greater loss of chemical from diffusion in the laboratory tests than would obtain in industrial practice.

In order to gain some idea of what additional expense the mills would consider practical for safeguarding pulp to be stored for any considerable time, a number of questionnaires were sent out in May, 1921. Twenty-three replies were received. The estimates of the nine companies submitting definite figures varied from $1.25 to $6 per ton, the average for maximum figures being about $3.50. On this basis only three of the preservatives suggested herein would be available, namely, cymene-naphthalene mixture, sodium dinitrophenolate, and sodium dichromate; but improved methods of applying the preservatives, so that a greater amount will be retained by the pulp, may hereafter permit the use of lower concentrations and thus make possible the use of some of the more expensive chemicals.

SUMMARY

An extensive survey of storage conditions at pulp and paper mills indicates that serious losses occur both in stored wood and in pulp, especially ground wood. Storage conditions in the woods and at the mill can be improved so as to reduce these losses.

The deterioration of wood and wood pulp is due mainly to fungi. For practical purposes these fungi may be divided into two general groups—molds and wood-destroying organisms. The former discolor the pulp but do not appreciably affect its strength; the latter produce true decay.

The character of the wood available for pulping is an important factor in its storage. Pulp wood usually consists of the less durable species. The length of storage, the time of cutting, the removal of bark, the presence of insects, methods of piling, and general sanitation about the yards are all conditions which affect the life of wood. The prevailing methods of storing wood are discussed in detail, and the desirability of segregating infected from sound wood and of pulping all wood in rotation is emphasized.

In order to demonstrate the difficulties met with and the large losses sustained in the use of decayed wood, a considerable amount of wood in various stages of decay was pulped by the mechanical, sulphite, and soda processes. The grinder runs on (spruce) wood which had been stored for three years under unfavorable conditions demonstrated a loss in yield of 16 per cent, based on weight of oven-dry barked wood. The resulting pulp was freer, contained a larger number of shives, and was decidedly darker in color than pulp made from sound wood. In the manufacture of chemical pulps, chipping losses ranged as high as 17 per cent for badly decayed material as compared with 4.4 per cent for sound material. The

NOTE.—Final conclusions as to the value of decayed wood, in general, for chemical pulp should not be drawn from the specific data presented in this bulletin. The value of decayed wood for sulphite pulp is closely associated with the chemical action of the wood-destroying organisms, and these organisms vary widely in their method of attack. Further investigations, under way at the Forest Products Laboratory, indicate already that some types of rot tend to reduce the value of wood for sulphite pulp less than the superficial appearance of the wood might suggest.

yields of screened sulphite pulp were not, as a rule, much lower than the yield from sound spruce. These yields, however, being figured on an oven-dry weight basis for both the wood and the pulp, do not represent the actual loss. If the yields per cord could have been determined, a distinct lowering with increased decay would have been demonstrated Soda cooks required more chemical for decayed wood than for sound, since the portion that had decayed was more readily soluble in the cooking liquor. When the pulp was undercooked, screenings were about 17 per cent, with a yield of only 32 per cent. In these experiments the chemical pulps from decayed woods were lower in strength, showed less endurance against folding, and were exceptionally dirty.

Chemical analyses of various sound and decayed woods explain the losses that occur through decay. The principal changes are marked increases in constituents soluble in hot and cold water and in alkali, indicating changes in the character of the cellulose from a resistant to a less stable form. The lignin does not appear to be destroyed in any appreciable amount. In the case of pulp (spruce, sulphite) made from decayed wood, decay is likewise reflected in increased solubility in water and NaOH and lessened stability of the cellulose. It is thus evident that a qualitative parallelism exists between decayed wood and the mechanical and sulphite pulps made from it.

In present commercial practice pulp is usually stored in large piles in the open or placed in closed unheated sheds or in the basements of mills. As a result of manufacturing conditions, ground wood is frequently stored for 6 to 12 months, or even longer. Chemical pulps are, for the greater part, converted immediately, or within a few months. Deterioration during storage is often severe, particularly with ground wood, and is due both to molds and to wood-destroying fungi. Molds, though not affecting the strength of the pulp, discolor it and frequently bind together the pulp particles so that the molded spots or areas do not beat up well, and a lumpy, speckled paper results. Wood destroyers decrease the strength of the wood fibers and render them so brittle that they break into short lengths in the beater, with the result that much of the pulp is lost in the white water and the manufactured paper has little strength. The combined action of molds and wood-destroying fungi thus results in the production of paper of very poor color and quality.

In order to combat deterioration of pulp during storage, careful attention must be given to the elimination of sources of infection. Pulp may become infected with molds either through the spores which abound in the air and in the water used in manufacturing processes, or by direct contact of moldy with clean pulp. Infection by wood destroyers more often occurs through contact with infected pulp or wood, but it may also occur through secondary spores produced on the fungus mycelium, or through spores of the more common type, produced on the fruit bodies which develop on wood in the form of conchs, brackets, toadstools, mushrooms, leathery incrustations, etc. Humus soil also appears to be an important source of infection for both molds and wood-destroying fungi. This may be carried about on the workmen's clothing or shoes.

The physical characteristics of pulp which has decayed in storage are similar to those of pulp made from badly decayed wood. Such pulp is much freer than sound pulp, is brash and brittle, foams badly, and tends to stick to the couch and press rolls. The paper made from it is considerably darker and much weaker than that from sound, and only one-tenth as resistant to ink penetration. Ground wood made from decayed wood deteriorates more rapidly during storage than that made from sound wood, in spite of the apparent destruction of most of the fungi in the original wood during the grinding process.

The most feasible method of controlling deterioration in pulp during storage, in addition to the adoption of the precautions against infection already indicated, is to introduce an antiseptic into the pulp on the wet machine. One hundred and twelve chemicals were tested for this purpose. About 3,000 small ground-wood laps and 1,400 sulphite laps were treated at the laboratory, and about 7,200 pounds of ground-wood pulp at the mill. The chemicals that best filled the requirements for a preservative were borax, boric acid, a solution of naphthalene in crude cymene, sodium fluoride, sodium dinitrophenolate, and sodium dichromate.

In the appendix will be found a record of studies, more comprehensive than any hitherto undertaken, of the fungi which inhabit pulp. Through these studies it was determined for the first time that the principal chemical damage to pulp is attributable to the hymenomycete fungi rather than to any of the molds. Sixteen hymenomycetes were isolated, but only one was completely identified, owing to the great difficulty of developing charactertistic fruit bodies in culture. The various fungi are described, and in addition to the morphological grouping there is presented a new scheme of classification of these fungi which is based on the color reactions of pulp infected by them.

In the appendix is also reported the first extensive investigation of the chemical action of fungi on ground-wood pulp.

APPENDIX

STUDIES OF SPECIFIC FUNGI THAT DETERIORATE WOOD PULP

Up to the present no careful systematic study of pulp-inhabiting fungi has been made. As far as is known by the writers, investigators in the past have ignored the hymenomycetes entirely, owing to the fact that before this study was undertaken no one used cultural methods in studying pulp fungi. The hymenomycetes can not often be detected by a mere examination of the pulp. Areas infected with them are commonly overrun by molds, which accounts for the fact that certain authors attribute serious decay of pulp to some of the molds.

In the course of the investigation a large number of fungi have been isolated from pulp and wood. In this appendix are presented the cultural characters of the fungi isolated, together with a classification of these fungi based on the color changes which they produce in the pulp.

Many of the organisms were grown on ground-wood pulp in order to determine their specific effect on the fiber. In general, it was found that the loss in weight produced by molds was slight, the greatest loss being 3.2 per cent in 12 months. Wood-destroying fungi (hymenomycetes), on the other hand, produced losses as high as 49.5 per cent within the same period. Analyses of the various samples showed that the effect of molds on the chemical constitution of the fiber was likewise slight, but that wood-destroying fungi produced very marked changes in this respect also.

WORK OF PRIOR INVESTIGATORS

Cellulose fermentation is the outstanding factor in the decay of both wood and pulp. It is known to be caused by certain hymenomycetes (among which are wood-destroying fungi), to a lesser extent by some of the fungi commonly called molds, and, more rarely, by certain groups of bacteria. The relative destructiveness of the first two groups, so far as concerns pulp in particular, has only lately been recognized—although for 70 years or more the general subject of cellulose fermentation has repeatedly attracted the attention of investigators. In 1850 Mitscherlich (*17*) first attributed the fermentation of cellulose to microorganisms. Workers immediately following Mitscherlich interested themselves not in the organisms causing cellulose fermentation, but rather in the products these organisms formed in the fermentation processes. After about 25 years investigators became interested in the organisms themselves, but more attention was then given to bacteria than to fungi.

To Van Iterson (*13*) belongs the credit for the first systematic study, as late as 1904, of cellulose fermentation induced by fungi. His method was the following: Two sterile sheets of pure filter paper were placed in a Petri dish and moistened with tap water in which ammonium nitrate and monobasic potassium phosphate were dissolved in the ratio 100: 0.05: 0.50; for inoculation, soil or humus was used, or the dishes were exposed to the air. The species were then separated on malt gelatin and tested for their cellulose-fermenting ability. Many active cellulose destroyers were thus obtained. In order to determine the abundance of mold spores in the air, Van Iterson exposed in the garden for 12 hours a Petri dish having a surface of 275 square centimeters and containing moistened filter paper. One hundred and fifty-two mold colonies developed, representing 35 different species. Fifteen cellulose destroyers in all were isolated and described in the course of this first investigation.

McBeth and Scales (*16*) list 16 different species as being able to destroy cellulose more or less rapidly, and point out that fungi are not so largely confined to acid soils as is generally believed. They hold that cellulose destruction in soil is largely due to the work of filamentous fungi.

Hartig (*9*) and a large number of other workers have recognized the part that the higher fungi, the hymenomycetes, which we commonly call wood-destroying fungi, play in the destruction of cellulose and other constituents of wood.

Of the fungi which infect wood pulp, however, very few investigations have heretofore been made, although notes concerning the deterioration of paper date back to the early part of the eighteenth century. At that time, and until recently, the spotting of paper was attributed to the work of larvæ.

In 1896 Klemm in Germany (*14*), published a short paper in which it is stated that the most common, as well as the most detrimental, of pulp-inhabiting fungi is *Rhynchosphaeria* sp. This mold is reported as appearing either as brown or dark-green spots with dark centers from which radiate delicate branched threads, or as numerous spots grouped together in blotches or in parallel lines of a gray color. Klemm attributed the uneven distribution to the mode of infection. This fungus, he showed, is propagated by two kinds of spores—ascospores, produced in asci (sacs) in perithecia, minute flask-shaped bodies with long narrow necks; and dark colored cells (chlamydospores) produced in chains in the mycelium. Chlamydospores are by far the more common. The perithecia were seen only occasionally on the surface of old pulp.

Klemm pointed out, also, that some organisms, although very destructive, are difficult to detect because they produce no discoloration. Pulp thus infected produces a paper which may rapidly become weak and brittle. It is quite evident that these fungi are the true wood destroyers, hymenomycetes, but Klemm did not seem to recognize them as such. He noted that *Stachybotrys atra* Cda., a "sooty" mold, is frequently present in large quantities, and that its spores cause a perceptible darkening of the pulp. Mention is made also of a mold, found on old pulp, which forms small, black, globe-like bodies surrounded by a yellow or brown spot. The conclusion is reached, however, that both this mold and *Stachybotrys atra* are relatively harmless, since their mycelia do not pierce, but only interlace, the wood fibers.

Barnes (*2*), while working as chemist for a large paper mill, observed mechanical wood pulp which was seriously damaged by rot—some of it rendered 20 to 25 per cent soluble in water and utterly ruined.

During three years many shipments of Scandinavian and Canadian pulps received were more or less damaged by "fungoid growth and rot." Microscopic examinations of the pulps were made, in an attempt to determine the cause of the deterioration. Barnes stated that the chief effect was a blackish discoloration produced by a species of Cladosporium, which he held responsible in most cases for the systematic decay of ground-wood pulp. There is shown a rough drawing of a "type of white fungus growing on the surface of the sheets in the interior of a bale of mechanical pulp." This was probably a hymenomycete. He considered the "fission fungi" (evidently, to judge from his figure, *Penicillium* sp.) to be the cause of the rapid decay of external parts of laps already infected with *Cladosporium* sp. He noted molds producing brick-red, yellow, and violet pulp, but remarks that they had very little "tendering" effect upon the pulp. In one series of tests various conspicuous spots were marked on the laps with a violet pencil; the marked laps were then piled in a compact stack and surrounded by moist sound ground wood. At the end of the six weeks it was found that all spots, including the "grayish markings due to reaction of iron and tannin bodies," had increased in size, and that the white branching fungus had grown far into the bale.

Sée (*24*) has made a rather thorough study of the fungi found on paper. He isolated 27 species belonging to 16 genera. As to their source, he states that the spores of the fungi are in the paper when it is made, but apparently he made no tests to substantiate his assertion. The assumption is based upon the presence of the same species on both paper and pulp.

Moreau (*18*) reports a very much blackened condition of imported pulp, supposedly due to the presence of a sphaeriaceous fungus. He advised that antiseptic measures be taken before shipping, because the presence of large quantities of the fungus would necessitate the use of excessive amounts of hypochlorite for bleaching.

In the review (*4*) of the work of Beadle and Stevens the most interesting fact, from the present standpoint, to be developed is that blue stain, caused by *Ceratostomella* spp., sometimes gives rise to trouble in paper making. The authors are inclined to believe that these species have a weakening effect upon mechanical pulp. Their spores are produced in long, beaked perithecia at the ends of logs or in cracks and holes.

The only hymenomycetes reported in the literature as inhabiting pulp are *Paxillus panuoides* Fr. and *Trametes serialis* Fr., observed by Von Schrenk at Glens Falls, N. Y. (*21*), whereas in the present investigation it has been conclusively shown not only that the hymenomycetes are present but also that they are responsible for the greatest amount of damage to pulp. It seems probable that had careful culture experiments been run, the previous investigators would have found hymenomycetes mixed with such molds as Rhynchosphaeria and Cladosporium, which they reported responsible for pulp decay. Without isolation studies it would have been easy indeed to mistake the more evident molds for the really destructive hymenomycetes.

MATERIALS AND METHODS EMPLOYED

In the study here reported, fungi were isolated from 18 samples of ground wood, 5 samples of sulphite pulp, 1 sample of soda pulp, 8 pulp logs, 7 boards taken from pulp sheds, 1 sample of white water, and 4 samples of river water. Although no attempt was made to obtain in pure culture all of the fungi that are in any way responsible for the deterioration of wood pulp, the writers nevertheless feel confident that they have isolated all of the more serious enemies common to pulp in the localities from which pulp samples were received. These samples, either in single laps or in larger amounts up to approximately half a ton, were submitted from mills in New York, Wisconsin, Minnesota, and Canada. Other samples of water were plated out, but since they yielded neither cellulose-dissolving molds nor hymenomycetes, no further study of them was made, nor were the cultures which they produced retained.

All culture work was performed in a culture case kept sterile by careful washing out with mercuric chloride solution (1:1000) before each using.

For general purposes, plain malt agar, made up according to the following formula, was found to be a very favorable medium:

Distilled water .... cubic centimeters..	1, 000
Trommer's plain malt extract .... grams..	25
Agar-agar, powdered or Bacto (acidity not adjusted) .... do....	15

Approximately 20 cubic centimeters were put in each test tube. After sterilization the medium was poured from the tubes into sterile Petri dishes, 3 or 4 drops of 5 per cent lactic acid having been added to half the tubes just prior to pouring. Both plain and acidified plates were then used in plating out the pulp samples. In special cases, in which the fungus could not be made to grow upon the plain malt medium, potato, carrot, bean, prune, and oatmeal agars were tried. In no case, however, were cultures obtained on these special media when they would not grow on the plain malt agar. For making cultures from river water, McBeth and Scale's cellulose agar was used.

Characteristic spots on the pulp were selected. In the comparatively few cases in which surface spores were present, a platinum loop full of sterile water was brought into contact and the adherent spores were transferred to a sterile tube containing about 2 cubic centimeters of distilled water. After a thorough shaking of this first tube further dilutions were made. Then a few drops of the spore suspensions were poured upon plain malt and acidified plates, and each plate was shaken gently until the entire surface was covered with a thin layer of the water. The plates were then incubated at 25 to 30° C. for the necessary period, which varies considerably with the various species of fungi. If the colonies on the plates were fairly uniform and sufficiently scattered, some of them were transferred to malt slants before any of them had sporulated. If mixed cultures were obtained, as was usually the case, the best plates were held until the desired fungus sporulated, when more plates would be made from it and the process repeated until pure cultures were obtained.

On the majority of the pulp samples, however, the spots were apparently pigmented or bleached areas with no superficial spores, and the process above described was not applicable. In such instances the more isolated spots were selected. The outer layers of the pulp were carefully folded back with a sterile needle, and some of the infected pulp from the interior of the sheet was transferred to plain malt and acidified plates. Usually three of each kind of plates were inoculated, but when the infection of the pulp was unusually heavy many more were used. If the spots were produced by molds, single spore cultures were made as soon as the fungus sporulated.

The hymenomycetes were much more difficult to isolate. The plates were observed frequently, and as soon as the transfer grew sufficiently other plates were made from the mycelial growth around it. Great care was taken to avoid the mycelia of any molds which might be present. It is seldom indeed that a piece of pulp is infected with a hymenomycete without being also more or less infected with various molds, and vice versa. It is frequently necessary to make many transfers before microscopic examination shows a pure culture. Welcome exceptions were several hymenomycetes which produce oidia, chlamydospores, or basidiospores; from these, single spore cultures could be made almost as easily as from the molds.

In working for pure cultures of pulp fungi, the greatest difficulty was caused by an overrunning of the plates by rapidly growing molds before other fungi could start growth. The most troublesome of these molds were species of Trichoderma and Mucor, which accounted for the loss of hundreds of plates. Some species of the former genus were almost invariably present and in a sporulating condition on deteriorating pulp.

Although bacteria probably play some part in the decay of wood pulp, it is quite evident from the studies made that they are not as important a factor as might be expected. There are perhaps two good reasons why this is true. Most cellulose-dissolving bacteria require (1) an abundance of moisture, and (2) a slightly alkaline medium. Ordinary pulp storage conditions would not satisfy the first condition, and ground-wood and sulphite pulps, which are slightly acid, do not afford the second.

FUNGI OBSERVED

Although molds, by which term all fungi except the hymenomycetes are referred to here, are more numerous and occur more frequently, they cause much less damage to pulp than do hymenomycetes. When molds are present, however, hymenomycetes are very likely to be found.

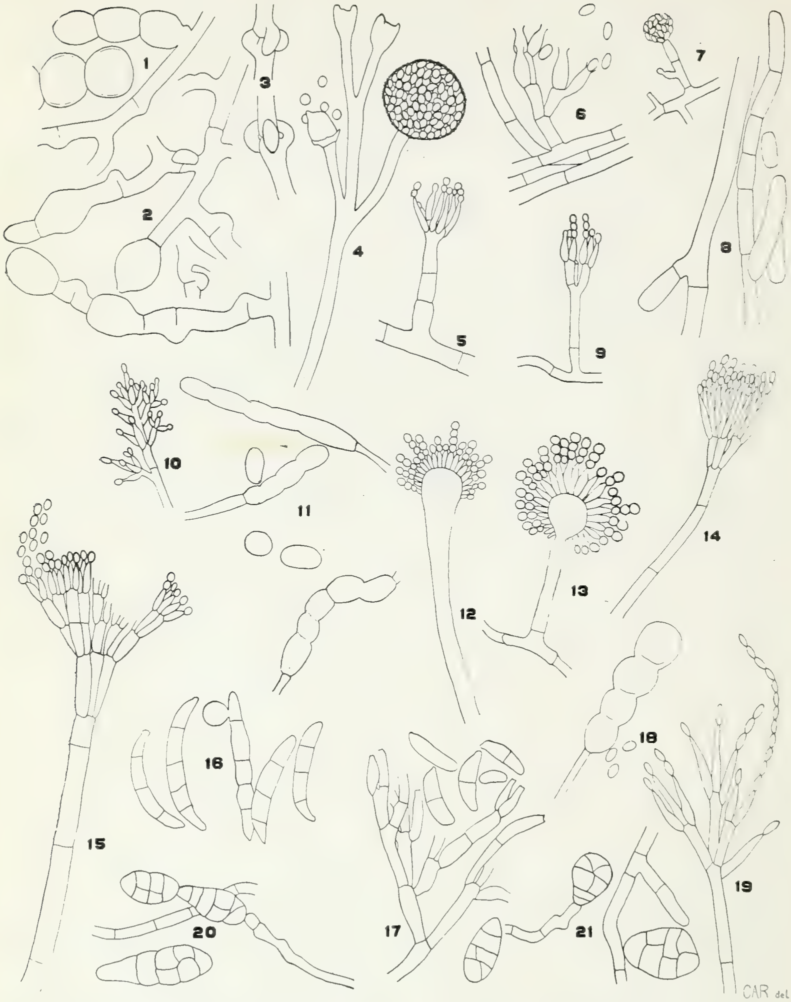
The most common of all the fungi observed are molds with large, dark-brown mycelia which interlace the wood fibers and produce a neutral gray or olive-black blotch in the pulp. At times the infection spots coalesce, and large gray or blue-black areas are formed. Several species of fungi produce such spots, and it is impossible to distinguish between them except by cultural methods. Blotches pink to purple in hue are found less frequently. They are produced by species of Penicillium and Fusarium. Only rarely have these molds been found sporulating on the pulp. Large yellow blotches are frequent in occurrence, most of them being indicative of some species of Trichoderma. Pinkish cinnamon spots are quite common, and are caused either by a mold or by any of several wood-destroying fungi (hymenomycetes). It is often difficult to distinguish between the two types, especially in the early stages of infection. From small

FIG. 1.—Section of small lap of ground-wood pulp treated with dry naphthalene at the rate of 50 pounds per ton of dry pulp and stored for 13½ months in pulp shed. Note clean condition under flakes of naphthalene and molded condition elsewhere

FIG. 2.—Section of commercial lap of ground-wood pulp sprayed with cymene at the rate of 2 pounds per ton of dry pulp and stored for 10 months in pulp shed. Note the severe molding

FIG. 3.—Section of commercial lap of ground-wood pulp sprayed with cymene and naphthalene mixture (50:50) at the rate of 4 pounds per ton of dry pulp. Stored for 10 months in pulp shed. Note perfect condition

FIG. 4.—Section of commercial lap of ground-wood pulp stored 10 months in pulp shed. Note the severe molding and decay



DRAWINGS OF REPRESENTATIVE FUNGI ISOLATED FROM WOOD PULP (X 120, EXCEPT FIG. 4)

FIGS. 1-3.—Mycelium and chlamydospores of hymenomycetes
FIG. 4.—Sporangiophore of *Mucor plumbeus* (X 55)
FIG. 5.—*Citromyces* sp., conidiophores and spores
FIG. 6.—Culture 81318-1, conidiophores and spores
FIG. 7.—*Trichoderma* sp., conidiophores and spores
FIG. 8.—Oidia and mycelium of *Oidium* sp.
FIG. 9.—*Penicillium* sp., conidiophores and spores
FIG. 10.—*Verticillium* sp., conidiophores and spores
FIG. 11.—Chlamydospores of *Torula* sp.
FIG. 12.—*Aspergillus fumigatus*, conidiophores and spores
FIG. 13.—*A. niger*, conidiophores and spores
FIG. 14.—*Penicillium* sp., conidiophores and spores
FIG. 15.—*Gliocladium* sp., conidiophores and spores
FIG. 16.—Spores of *Fusarium* sp.
FIG. 17.—*Fusarium* sp., conidiophores and spores
FIG. 18.—Chlamydospores and microconidia of *Fusarium* sp. Spores and mycelium
FIG. 19.—*Spicaria* sp., conidiophores and spores
FIG. 20.—*Alternaria* sp., conidiophores and spores
FIG. 21.—*Stemphylium* sp., conidiophores and spores

round brown spots, very commonly found, a species of Alternaria has been isolated consistently. Not all such spots, however, are produced by the same fungus.

Several of the molds commonly inhabiting pulp produce no pigment, have a colorless mycelia, and so are evident only when they sporulate. Among these were identified species of Gliocladium, Penicillium, Citromyces, Trichoderma, Aspergillus, and Mucor.

Brown blotches are produced by several species of molds and by some hymenomycetes. Generally speaking, the hymenomycetes produce areas of some shade of brown, varying from a faint pinkish cinnamon to a brown-black, though some produce cream-colored or bleached areas. The areas of pulp infected with hymenomycetes may be very weak. They may be much thinner than the surrounding portions of the pulp oftentimes falling out entirely when the pulp is moved.

Many of the cultures have not as yet been identified. Those isolated from pulp and water are listed as follows:

- *Phycomycetes*
  - *Mucoraceae*
    - *Mucor plumbeus* Bon.
    - *Mucor racemosus* Fres.
    - *Rhizopus nigricans* Ehrenb.
- *Ascomycetes*
  - *Pezizaceae*
    - *Peziza repanda* Wahl.[1]
  - *Mollisiaceae*
    - *Orbilia rubella* Pers.[1]
  - *Sphaeriaceae*
    - *Chaetomium globosum* Kunze[1]
    - *Chaetomium funicolum* Cooke[1]
- *Basidiomycetes*
  - *Hymenomycetes*
    - *Agaricaceae*
      - *Paxillus panuoides* Fr.
    - 15 unidentified cultures, discussed hereinafter.
- *Fungi imperfecti*
  - *Sphaerioidaceae*
    - *Cytosphora* sp.
  - *Mucedinaceae*
    - *Torulopsis rosea* Berl.
    - *Oidium* sp.
    - *Papulospora nigra* Hotson
    - *Trichoderma* spp. (11 cultures)
    - *Aspergillus niger* van Tiegh
    - *Aspergillus fumigatus* Fres. (2 cultures)[1]
    - *Aspergillus flavus* group (2 cultures)[1]
    - *Penicillium pinophilum* Hedgc.[1]
    - *Penicillium purpurogenum* O. Stoll[1]
    - *Penicillium brevicaule* series[1]
    - *Penicillium commune* Thom[1]
    - *Penicillium* spp. (13 cultures)
    - *Citromyces* spp. (2 cultures)[1]

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[1] ACKNOWLEDGMENT.—The late Dr. E. J. Durand and Drs. A. H. Chivers, Charles Thom, and Margaret B. Church rendered aid in identifying these fungi.

Fungi imperfecti—Continued
  Mucedinaceae—Continued
    Gliocladium sp.
    Verticillium sp.
    Spicaria sp.
    Unidentified *Mucedinaceae* (1 culture)
  Dematiaceae
    Torula sp.
    Thielaviopsis sp.
    Stemphylium sp.
    Alternaria spp. (2 cultures)
    Unidentified *Dematiaceae* (22 cultures)
  Tuberculariaceae
    Fusarium spp. (9 cultures)

None of the hymenomycetes which are commonly found on pulp wood have been isolated from pulp, although the following species obtained from pulp wood or from boards taken from pulp sheds grew when planted on pulp: *Fomes roseus* Fr., *Lentinus lepideus* Fr., *Peniophora tabacina* Burt., *Stereum sanguinolentum* A. and S., *Corticium galactinum* Fr., and six undetermined species (cultures 4620–3, 4620–4, 61420–3, 61420–4, 61420–5, 61420–7). (See Table 16.)

DESCRIPTION OF CULTURES OBTAINED FROM PULP AND WATER

PHYSOMYCETES

MUCORACEAE

It is probable that several species of the Mucoraceae grow on pulp, but for the reasons that they seem to be superficial, do not produce a definite discoloration, and generally do not produce spores in numbers large enough to damage the pulp, little attention was given this group. Only three species, which occur frequently, have been isolated.

Mucor plumbeus Bon.—Mycelium submerged, hyaline; chlamydospores common, hyaline to light brown;[5] sporangiophores upright, about 1 centimeter high, branches cymose or irregular, forming a hoary turf in young cultures; sporangia at first gray then olive black, walls very finely aculeated (Pl. XVI, fig. 4); columella cylindrical or pyriform, with one or more tapering or blunt spines on top; spores globose, light brown. Isolated from soda pulp. Very common on all kinds of pulp.

Mucor racemous Fres.—Mycelium submerged, septate; chlamydospores frequent; sporangiophores upright, very short, 1 to 5 millimeters, septate, branched, cymose or irregular; sporangia small, white then blue-gray, walls very finely aculeated; columella hemispherical or short cylindrical; spores light brown. Isolated from ground wood. Common.

Rhizopus nigricans Ehrenb.—Aerial mycelium white, aseptate, becoming dark and septate in very old cultures; rhizoids numerous; sporangiphores fasciculate, erect, aseptate, arising from the nodes; sporangia globose, olive black; columella hemisperical; spores gray

[5] Colors used in the following descriptions have, in most cases, been matched as closely as possible with Robert Ridgway's Color Standards and Color Nomenclature, 1912.

to brown, black en masse, subglobose or irregular. Isolated from soda pulp and ground wood (82219–10).[6] Almost always present on damp pulp. This is the common black bread mold, which may be obtained at any time by exposing a culture plate or a moist piece of bread to the air.

ASCOMYCETES

PEZIZACEAE

Peziza repanda Wahl.—Mycelium white to cream colored, forming a rather thin, uneven layer over the agar, septate and colorless when growing in the pulp and causing no perceptible change in it; apothecia (fruit bodies) disk-shaped, cream-colored, 4 to 30 millimeters in diameter. Collected once from ground wood in a very wet place. Apothecia were also produced on the floor and shelves in the same pulp shed.

MOLLISIACEAE

Orbilia rubella Pers.—Apothecia small, 1 to 3 millimeters, light pink. Collected once on a very rotten pulp. Not isolated.

SPHAERIACEAE

Chaetomium spp.—Mycelium hyaline, does not discolor the pulp, and apparently does little damage.

Chaetomium globosum Kunze—Culture gray; perithecia rather large; lateral hairs numerous, slender, slightly undulate, obscurely septate, minutely roughened, dark olive brown at base, lighter at tip; terminal hairs numerous, spreading and drooping, slender, aseptate, minutely roughened, dark olive brown with tapering yellow or hyaline tips, wavy. Spores olive brown, ovate, or subglobose. Isolated from sulphite pulp. Observed twice.

Chaetomium funicolum Cooke—Culture gray blue-green; perithecia smaller; lateral hairs few, straight, rigid, septate, tapering to collapsed tip, olive brown at base to hyaline at tip; terminal hairs profusely branched dichotomously, with branches reflexed, roughened, dark olive brown at base to hyaline at tips; spores light olive brown, ovate to lemon shaped. Isolated from ground wood. Observed once.

HYMENOMYCETES

AGARICACEAE

Paxillus panuoides Fr.—Mycelium white, becoming light cream with age, forming compact sheets over the surface of the medium. (See Pl. XVII, fig. 2.) In slant cultures, and sometimes in plate cultures, fairly large compact masses of hyphæ are produced. The sporophores are more or less fan shaped, either sessile or with a very short lateral stipe. (See Pl. XVIII, figs. 1 and 2.) They are pure white on top when fresh, becoming yellowish with age, yellowish brown below. The spores are yellowish brown. This is one of the hymenomycetes which produces "red rust" or "red rot" in pulp. It is the only one found on this occasion producing sporophores on pulp. It colors the pulp pinkish buff or cinnamon buff to cinnamon (dry),

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[6] The culture numbers are given for those fungi which were used to obtain the data shown in Tables 13, 14, 15, 16, and 17.

or mikado brown to russet (wet). Pulp infected with this fungus becomes very brittle. Isolated from "red-rusted" pulp, later from a sporophore which developed on the same lot of pulp when placed in a sterile Wardian case. This is the only hymenomycete which was found producing a fruit body. A very common species.

UNIDENTIFIED HYMENOMYCETES

In the absence of fruit bodies, which (with the exception above noted) the investigators were unable to find on pulp or to develop in culture, there is no way by which cultures of hymenomycetes may be identified except by comparison with cultures of known fungi. Although these species were compared with large numbers of known hymenomycetes in pure cultures, none was definitely identified. For convenience they will be grouped as follows:

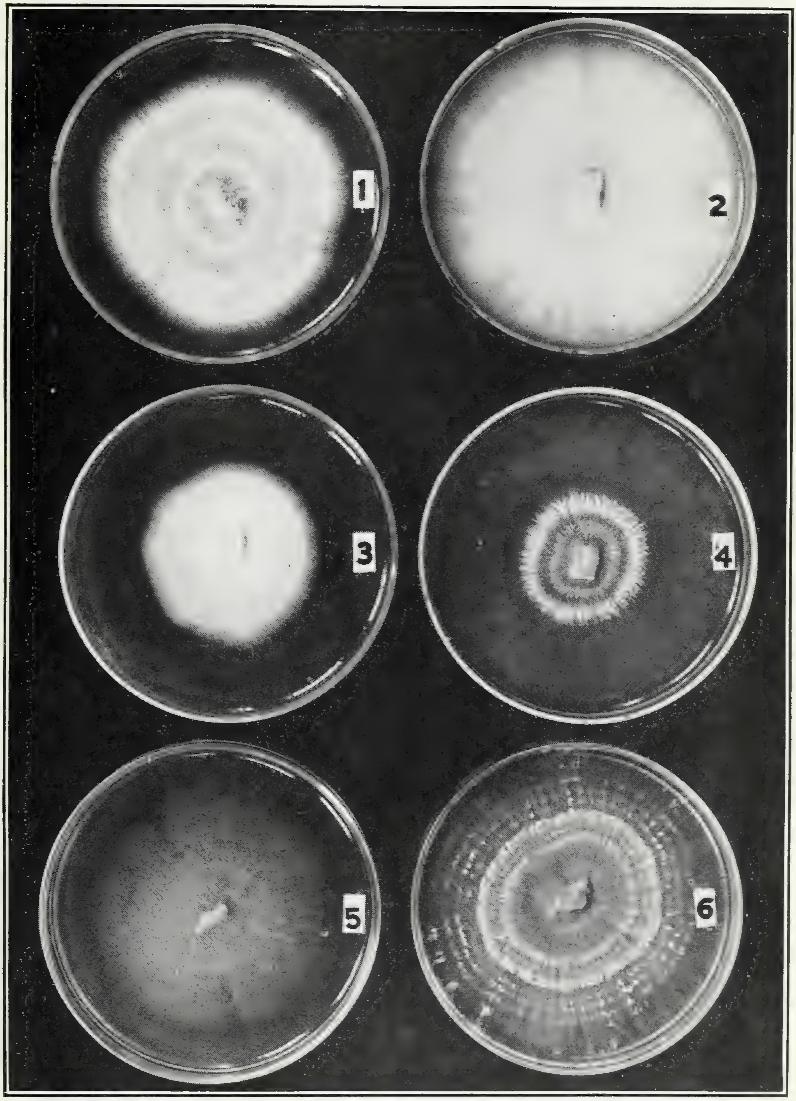
1. Four cultures varying but slightly; mycelium soggy, appressed, forming compact sheets over the agar; large, conspicuous clamps; barrel-shaped or globose interstitial and terminal chlamydospores (Pl. XVI, fig. 1), in more or less regular zones in Petri dish cultures, white or cream colored, narrow or wide (Pl. XVII, figs. 4 and 6). These fungi bleach pulp somewhat, but are not vigorous wood destroyers. Isolated from ground-wood (10918–10, 102019–1a, 6320–1) and sulphite pulp. Very common.

2. One culture; mycelium soggy, appressed; differs from 1 in that the mycelium does not form such compact sheets over the agar; chlamydospores in more or less distinct radiating lines. (See Pl. XVII, fig. 5.) In older cultures small white tufts of mycelium appear, scattered sometimes over the surface, but more frequently around the edge of the plate. In jar cultures, and sometimes in slants, dense masses of chlamydospores are formed on the surface of the glass. (See Pl. XIX, fig. 1.) Chlamydospores barrel shaped, ellipsoid, or somewhat lemon shaped, terminal or intercalary. Clamps conspicuous. (See Pl. XVI, fig. 2.) Areas are cream-colored when freshly infected, but become pinkish buff (dry) to clay color (wet), buffy brown (dry) to olive brown (wet), and finally mummy brown (dry) to dark clove brown (wet). This fungus causes great damage which, in severe infections, may become an entire loss, the pulp becoming so brittle that it can not be used. (See Pl. XIX.) Isolated from ground wood (82219–15). Common on ground wood and observed once on sulphite pulp.

3. Two cultures very nearly alike; mycelium soggy, appressed; chlamydospores in creamy masses or in small white mealy specks. Newly infected areas cream-colored, later pinkish buff (dry) to cinnamon buff (wet), tawny olive (dry) to Chaetura black (wet). Infected pulp very friable, useless. Isolated from ground wood (4620–1, 4620–2). Common.

4. One culture; mycelium appressed, soggy, forming compact sheet; clamps conspicuous; no chlamydospores. Does not discolor the pulp and causes very little damage. Isolated from sulphite pulp (6920–2). Observed once.

5. One culture; mycelium appressed, soggy, forming compact sheets over surface of plates, with here and there fluffy white bunches of mycelium; clamps conspicuous; maize yellow, ellipsoid or globose chlamydospores produced on surface, forming a yellow mealy mass.



PETRI-DISH CULTURES OF HYMENOMYCETES ISOLATED FROM GROUND-WOOD PULP

FIGS. 1–5.—Ten-day-old growth:
FIG. 1.—Culture No. 92219–4
FIG. 2.—*Paxillus panuoides*
FIG. 3.—Culture No. 82219–13
FIG. 4.—Culture No. 102019–1a
FIG. 5.—Culture No. 82219–15
FIG. 6.—Twenty-four-day-old growth of culture No. 102019–1a (cf. fig. 4)

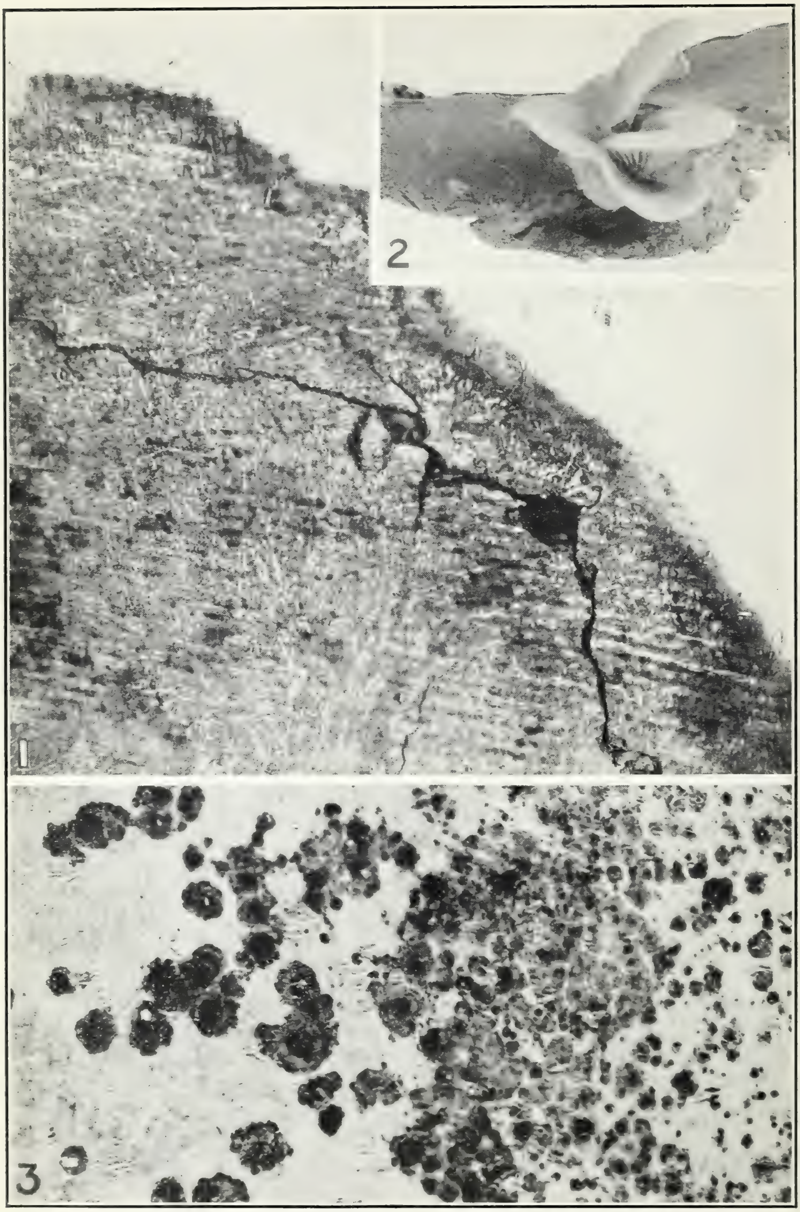


FIG. 1.—Portion of a lap of ground-wood pulp rotted by *Paxillus panuoides* during a six months' storage period in the basement of a New York mill. This type of rot is frequently termed "red rust)"

FIG. 2.—Fruit bodies of *Paxillus panuoides* developed at the laboratory from the samples of "red-rusted" pulp shown in fig. 1

FIG. 3.—Ground-wood pulp severely molded during six months' storage in the basement of the mill referred to under fig. 1

Pulp is not discolored by this fungus, except that the yellow chlamydospores are formed on the surface. It causes little damage. Isolated from ground wood (61520–1). Observed once.

6. One culture forming a loose silky layer over the surface of medium and a very fluffy white margin. In old cultures the mycelium sometimes becomes cinnamon colored. Glistening droplets appear on the mycelium. White to cinnamon buff, warty hymenial patches are frequently formed on plate cultures. This fungus turns the pulp pinkish buff (dry) to cinnamon buff (wet). It causes considerable loss in weight and makes the pulp very brittle. Isolated from ground wood (61020–1). A similar culture was isolated from spruce pulp wood. Observed once on pulp.

7. One culture with loose, fluffy mycelium, white, later becoming tinged cinnamon buff; no clamps; no chlamydospores. Macroscopically this culture has all the characteristics of a hymenomycete. Infected areas become pinkish buff (dry) to clay color (wet), with scattered depressed white spots. It causes considerable loss in weight in the pulp. Isolated from white water (62220–1). Observed once.

8. One culture with loose, fluffy, white mycelium, later becoming cinnamon buff. Some hyphæ are very large, with whorls of large clamps (Pl. XVI, fig. 3); no chlamydospores. Bleaches the agar.[7] Newly infected areas are pinkish buff (wet), later becoming deep mikado brown. Isolated from fresh river water. Observed once.

9. Two cultures of a loose, fluffy, white fungus, which on Petri-dish cultures produces rather compact zones of basidia bearing basidiospores. (See Pl. XVII, fig. 1.) There is only a very slight difference between the two cultures, and they are probably two strains of the same species. Conspicuous clamps; chlamydospores. These fungi turn the pulp light ochraceous buff (dry) or ochraceous tawny (wet). A fine mottling with white depressed spots is noticeable in the older infected areas. These fungi cause considerable loss. Isolated from ground wood (82219–4, 6920–1). Common.

10. One culture producing long, fine, white radiating mycelial strands. (See Pl. XVII, fig. 3.) It produces brown sclerotia-like bodies. Conspicuous clamps; no chlamydospores. This fungus produces no discoloration of the pulp, but its presence is made evident by the long, glistening loose strands of mycelium found on opening up a lap of pulp infected with it, and by the sclerotia-like bodies. It causes only slight loss of weight in the pulp. Isolated from ground wood (82219–13). Common on ground wood, and observed once on sulphite pulp.

Fungi Imperfecti

SPHAERIOIDACEAE

Cytospora sp.—Culture at first white, with scanty mycelium gathered in bunches, later becoming deep slate olive, reverse black; hyphæ hyaline to deep brown; sharply defined stroma containing several pycnidia; conidia hyaline, allantoid, minute. Agar normal; pulp deep blue-slate-black. Isolated from sulphite pulp. Rather common.

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[7] All culture characters given are those present when the fungi are grown on plain malt-bacto agar.

MUCEDINACEAE

Torulopsis rosea Berl.—Hyphæ obsolete; cells ellipsoid or globose, rose-colored en masse, usually budding at the ends, seldom forming chains. Agar normal; pulp slightly pink. Isolated from ground wood. Common.

Oidium sp.—Cultures wet and mucilaginous, occasionally mealy; septate hyphæ irregularly branched, more distinct than is usual in Oidium, but they break up into typical oidia (simple segmentation of the hyphæ). The oidia vary considerably in length; are at first cylindrical, but when separated become rounded at the ends. (See Pl. XVI, fig. 8.) This fungus causes little damage to the pulp. Infected areas are generally lighter in color than normal pulp. This fungus is probably responsible in part for pulp in very wet condition souring. Isolated from ground wood (62020–1). Common.

Papulospora nigra Hotson.—Mycelium scanty, white, becoming dirty gray in very old cultures, clamp connections conspicuous; bulbils colorless when young, becoming dark brown, then black, at maturity (Pl. XX, fig. 1), produced in large numbers, soon making entire culture appear black. No other means of reproduction known. The clamps indicate the relation of this species to the hymenomycetes. Hyaline mycelium penetrates the pulp; black bulbils are produced on surface. Isolated from ground wood (32019–7). Rather common.

Trichoderma spp.—Nine cultures varying enough to be of distinct species were isolated. Mycelium scanty, cottony, white or yellow, or compact, soggy, appressed, cream-colored to yellow; conidia in heads at tips of the many branches of the fertile hyphæ (Pl. XVI, fig. 7), scattered uniformly over surface, in small or large patches, or around the margin; conidia white, bluish gray, or reed-yellow to light or dark American green. Agar normal, yellowed, or browned; infected pulp normal in color, yellow or green. These species produce large masses of spores, most of which are American green, and make the pulp "dirty." Some cultures dissolve cellulose. Isolated from ground wood (82219–10, 32019–1), from sulphite pulp, from river water (6520–2). All very common.

Trichoderma sp.—Mycelium scanty, white, rapidly covering the surface of the agar; small, white, compact bunches of conidiophores, appearing early, scattered over the surface. As conidia mature these patches become pinkish cinnamon and, finally, cinnamon. This fungus causes a slight browning of the pulp. Isolated from ground wood (10918–4). Observed twice.

Aspergillus spp.[8]—This group produces globose conidia in chains at the tips of sterigmata, which in turn are born on the inflated heads of the fertile hyphæ. (See Pl. XVI, figs. 12 and 13.) None of the species discolor pulp, but all sporulate abundantly on the surface.

Aspergillus niger van Tiegh.—Mycelium scanty, superficial; but next to the glass, in slant culture, there is often a naphthalene yellow or citron-yellow sheet. The surface of cultures is soon covered with a coal-black, powdery mass, formed by conidia. Isolated from bleached sulphite and soda pulp. Very common. It is almost invariably present in the "sooty" blotches on pulp.

[8] Aspergillus and Penicillium should properly be classed with the ascomycetes, but since the ascigerous stage is known for only a few, they are often placed with the fungi imperfecti.

Aspergillus fumigatus Fres.—(1) Mycelium sparse, superficial, white; entire surface covered with dark bluish gray-green spores which become deep slate olive in old cultures. Agar greenish yellow. This fungus dissolves cellulose. Isolated from river water (6520–1) Common. (2) No superficial mycelium; entire surface covered with dark bluish-gray conidia which become deep slate olive in old cultures. Agar purple-brown. Isolated from sulphite pulp. Common.

Aspergillus flavus group.—(1) No superficial mycelium; surface covered with parrot-green conidia which later become brownish olive. Isolated from sulphite pulp. Common. (2) Mycelium loose, fluffy, white, around the margin of young cultures, but soon covered with mignonette-green conidia which become brownish olive in very old cultures. Isolated from bleached sulphite. Common.

Penicillium spp.—Conidia globose or ellipsoid, borne in chains on the tips of sterigmata, which are small branchlets at the top of the unequally verticillately branched, uninflated fertile hyphæ. (See Pl. XVI, figs. 9 and 14.) Some of the species discolor the pulp; all of them produce spores in sufficient numbers to make the pulp "dirty." The species isolated may be described briefly as follows:

Penicillium brevicaule group.—Mycelium scanty, appressed, soon covered with pinkish buff to avellaneous conidia, which later become cinnamon brown. Agar slightly darkened; pulp not discolored. Isolated from ground wood (81318–2). Common.

Penicillium divaricatum group.—Mycelium scanty, superficial, soon covered by a smooth layer of conidiophores with light brownish-olive conidia. Agar very dark brown; pulp slightly browned. Isolated from ground wood. Common.

Penicillium pinophilum Hedgc.—Mycelium scanty, superficial when grown on malt agar. Cultures soon become dark bluish glaucous mixed with a little yellow-green due to conidia. Agar dark red; pulp pink to red. Seldom produces large numbers of spores on pulp, but the reddening is sufficient to give an off-color paper. According to Thom (*26*) it produces orange to red stains in pine wood. Isolated from ground wood (112217). Very common.

Penicillium purpurogenum O. Stoll.—Similar to *P. pinophilum* when grown on malt agar, but no yellow present in the spore surface, which is somewhat smoother. Agar red to purplish vinaceous in old cultures; pulp pink to purplish red. Isolated from ground wood (10918–11) and sulphite pulp. Very common.

Penicillium commune Thom.—Mycelium scanty, soon covered with celandine-green conidia, which become gnaphalium green or even dark olive. Older cultures more or less overgrown with white floccose mycelium. Agar and pulp normal. Isolated from ground wood (10918–3). Common.

Undetermined Penicillium species.—Nine cultures, varying enough to be distinct species, were isolated. Mycelium soggy, appressed, or cottony; floccose, scanty, or abundant; white, reed yellow, or colonial buff; conidia bluish gray-green, grayish blue-green, pistachio green, glaucous, citron or glass green to light brownish olive, ecru olive, mytho, dark ivy, or dark American green; surface dry, or covered with droplets of clear, amber, or pink liquid. Agar normal, yellow, green, or brown; pulp normal or slightly browned. One culture dissolves cellulose. Isolated from ground wood (10918–9, 82219–12), sulphite pulp, soda pulp, and river water (6520–3). All very common.

Two cultures similar to *P. pinophilum* but both producing black sclerotia-like bodies. Conidial surface as in *P. pinophilum*, or glass green to tea green. Agar red; pulp pink to red. Isolated from sulphite pulp. Each observed once.

One culture with mycelium white to cream-colored, cottony, soon covered with white ascigerous masses, conidial fructifications rather rare. Agar normal; pulp slightly browned. Isolated from ground wood. Observed once.

Citromyces sp.—Macroscopically appears like Penicillium, but distinguished by the somewhat inflated conidiophores bearing a single whorl of sterigmata. (See Pl. XVI, fig. 5.) Mycelium scanty, white, or soggy, appressed; conidia deep bluish gray-green, or deep glaucous gray. Agar normal or yellowish; pulp made "dirty" by spores. Isolated from ground wood (10918–6, 10918–12). Common.

Gliocladium sp.—Mycelium very scanty, loosely floccose; conidiophores Penicillium-like (Pl. XVI, fig. 15), except that they are widely scattered over the surface of the cultures so that no solid mass of them is found. Spores held in a deep American green mucus which is soluble in water and sometimes is produced in such amounts that the pulp becomes dyed with it. Isolated from ground wood (10918–1) and sulphite pulp. Very common in all kinds of pulp and river water.

Verticillium sp.—Mycelium sparse, superficial, hyaline or very light brown, soon covered with cinnamon-drab conidia borne singly at tips of loose verticillately branched conidiophores (Pl. XVI, fig. 10); conidia held together in heads. Pulp slightly browned. Isolated from ground wood. Common.

Spicaria sp.—Mycelium appressed, soon covered with white to cinnamon-buff fructifications. The conidiophores are branched in loose verticils (Pl. XVI, fig. 19), thus differing from Penicillium, which has close verticils. Underside of culture is brown, and in older cultures the agar becomes dark brown. Pulp browned. Isolated from ground wood (10918–5). Observed once.

Unidentified Mucedinaceae.—Several other Mucedinaceae were isolated from pulp, but since they caused no perceptible damage and were not common, notes on them are omitted from this report. One species which caused a yellowing of the pulp is described as follows: Culture deep colonial buff to tawny, appressed to downy; hyphæ hyaline to yellowish; some large, rigid, light yellow-brown filaments in clusters; many cylindrical oidia of various lengths. Agar and pulp, colonial buff to tawny. Isolated from sulphite pulp. Common.

DEMATIACEAE

Torula sp.—Hyphæ hyaline, soon becoming very dark brown, mostly submerged, breaking up into chains of one-celled, dark-brown spores. Pulp very dark neutral gray. (See Pl. XVI, fig. 11.) Isolated from sulphite pulp. Common on sulphite and ground-wood pulps.

Thielaviopsis sp.—Culture dull black, appressed, with white powdery masses on surface; hyphæ hyaline, then brown, breaking up into chains of one-celled, dark-brown chlamydospores; many hyaline, oidia-like conidia produced endogenously. Agar normal; pulp gray. Isolated from ground wood. Observed once.

Stemphylium sp.—Culture green-black, reverse jet-black; mycelium decumbent, hyaline to brown, scanty; conidiophores decumbent, irregularly branched; conidia large, muriform, very dark brown, mostly ovoid. (See Pl. XVI, fig. 21.) The brown hyphæ intertwine the fibers, producing olive-black areas in the infected pulp. The large, dark spores are frequently found in "sooty" spots. Isolated from soda pulp. Common.

Alternaria sp.—Culture velvety, pale to deep olive gray, reverse black; mycelium hyaline to brown; conidia obclavate, muriform, brown, single or in chains (12 spores have been observed in one chain) at the ends of conidiophores which vary but little from the regular hyphæ (Pl. XVI, fig. 20); chains sometimes branched. This species produces small, round, brown spots in ground wood. Isolated from ground wood (32019–2). Common.

Unidentified Dematiaceae.—Mycelium hyaline becoming brown, often in heavy decumbent strands.

1. Cultures dark olive gray or grayish olive to mouse gray, reverse black; conidiophores short, rarely branched, brown at base to subhyaline or hyaline at roughened tip (Pl. XX, fig. 2); conidia fusoid or ellipsoid, subhyaline to hyaline. Agar red-brown or normal; pulp gray. Isolated from ground wood (3818–1, 82219–5). Very common.

2. Cultures mouse gray, drab, or dark snuff brown, reverse brown-black; mycelium downy, cottony, or fluffy to feltlike; conidiophores branched or unbranched, lateral branches of ordinary hyphæ, hyaline to light brown, ends open to form a "collar" which is slightly flaring (Pl. XVI, fig. 6) and concolorous with conidiophore, bell shaped and dark brown (Pl. XX, fig. 3) or widely flaring, saucer shaped and dark brown (Pl. XX, fig. 4). Conidia borne singly at tips of conidiophores, held together in heads; hyaline, subhyaline, or light brown; ovoid, ellipsoid, or globose. Agar normal or bleached; pulp dark neutral gray, olive gray, or brown-black. Isolated from ground-wood (81318–1, 10910–7, 82219–18, 82219–2) and sulphite pulp. Very common.

3. Cultures olive brown to black, or mouse gray to dark grayish olive, reverse black; hyphæ dark brown, frequently coiled; conidiophores Penicillium-like, dark brown at base to hyaline at tips of final branches; conidia globose, small, hyaline, borne in chains at tips of conidiophores. Agar normal; pulp dark neutral gray. Isolated from ground-wood (82219–9, 82219–23) and sulphite pulp. Very common.

4. Culture soggy, appressed, cream to cinnamon; hyphæ hyaline; conidiophores short, rigid, septate, brown below branches, branched irregularly, tips hyaline; conidia hyaline, ovoid or ellipsoid, borne in short chains at tips of conidiophores. Agar normal; pulp cinnamon. Isolated from sulphite pulp. Rather common.

5. Cultures deep olive gray, reverse brown; mycelium hyaline or brown, sometimes in strands, not superficial; conidiophores short, rigid, brown at base, hyaline toward tips, branched in irregular whorls; conidia oidia-like, in chains at tips of conidiophores, hyaline. Agar slightly darkened; pulp olive gray. Isolated from sulphite pulp. Common.

TUBERCULARIACEAE

Fusarium sp.—Mycelium scanty, hyaline to light brown; chlamydospores brown, rough, globose; conidia mostly one or two celled. (See Pl. XVI, fig. 17.) Agar red; pulp orange vinaceous. Isolated from sulphite pulp. Observed once.

523°—25†——5

Fusarium sp.—Mycelium scanty, pinkish; no chlamydospores; sporodochia small, discoid, Mars brown; conidia one to five celled. Agar slightly purple; pulp deep purplish vinaceous. Isolated from sulphite pulp and ground-wood. Observed twice.

Fusarium sp.—Mycelium very scanty, white, no chlamydospores; sporodochia cream, light Terre Verte to neutral red; conidia mostly five celled, very few one celled. (See Pl. XVI, fig. 16.) Agar slightly red; pulp deep purplish vinaceous. Isolated from ground-wood. Observed once.

Fusarium sp.—Cultures mealy to subgelatinous, from white to pale cinnamon pink; hyphæ hyaline; numerous pink intercalary chlamydospores; spores abundant, small, ovoid, hyaline, apparently produced in clumps at ends of branches (Pl. XVI, fig. 18); very few typical Fusarium spores found; no well-defined sporodochia. Agar normal, pulp light pinkish cinnamon. Isolated from ground-wood (82219–1) and sulphite pulp. Very common.

CLASSIFICATION OF ORGANISMS BASED ON COLOR CHANGES IN PULP

The fungi just described have been grouped according to their morphology, which is the true mycological classification. In the following key the fungi are grouped according to their color reaction on pulp. This key is an attempt to present the fungi in such a way that those least familiar with them may be able to determine which organisms may be present and thus to decide whether an organism is a hymenomycete, causing a loss in the wood fiber, or a mold, producing simply a discoloration of the pulp. Each of the fungi investigated either (*a*) bleaches pulp, (*b*) causes no color change in the pulp, (*c*) produces a color change which may be due either to chemical disintegration of the pulp itself or to pigments produced by the fungi, or (*d*) produces a color change which is due to the colored mycelia which are scattered through the pulp. The key classifies the fungi described above according to these color effects, as follows:

- Organisms that bleach pulp.
  - Producing no superficial spores.
    - Hymenomycetes, *Oidium* sp.
- Organisms that cause no color change in pulp.
  - Producing no superficial spores.
    - Hymenomycetes.
  - Producing superficial spores.
    - Spores maize yellow.
      - Hymenomycetes.
    - Spores green or blue.
      - *Trichoderma* spp., *Aspergillus* spp., *Penicillium* spp., *Citromyces* spp., *Gliocladium* sp.
    - Spores black.
      - *Papulospora nigra*, *Aspergillus niger*.
    - Spores brown.
      - *Trichoderma* sp., *Penicillium* sp., *Verticillium* sp.
  - Producing superficial ascocarps (fruit bodies).
    - Asci in apothecia (open, saucer shaped).
      - *Peziza repanda*, *Orbilia rubella*.
    - Asci in perithecia (nearly closed, globose).
      - *Chaetomium globosum*, *Chaetomium funicolum*.

Organisms that cause spots in pulp not due to colored mycelia.
  Producing no superficial spores.
    Pulp some shade of buff, brown, or black.
      Hymenomycetes.
    Pulp pale pink.
      Torulopsis rosea.
  Producing superficial spores.
    Pulp some shade of red.
      Penicillium spp., *Fusarium* spp.
    Pulp some shade of yellow or green.
      Trichoderma spp., unidentified Mucedinaceae.
    Pulp some shade of brown.
      Trichoderma sp., *Penicillium* sp., *Spicaria* sp.
Organisms that cause spots in pulp, due in part at least to colored mycelia.
    Pulp light brown.
      Verticillium sp.
    Pulp dark brown.
      Alternaria sp., unidentified Dematiaceae.
    Pulp some shade of gray.
      Torula sp., *Thielaviopsis* sp., unidentified Dematiaceae.
    Pulp blue-slate-black.
      Cytospora sp.
    Pulp olive black.
      Stemphylium sp.

PHYSICAL AND CHEMICAL PROPERTIES OF GROUND-WOOD PULP DETERIORATED BY SPECIFIC FUNGI IN PURE CULTURES

PHYSICAL PROPERTIES

PREPARATION AND EXAMINATION OF SAMPLES

The series of tests to determine the specific action on pulp of various fungi in pure culture was comprehensive in scope, representing about half of the species isolated. The test medium was fresh, clean ground wood made up of spruce, 70 per cent, and balsam, 30 per cent. The pulp was cut up into pieces 2½ by 10 inches, all of which were oven dried (100 to 105° C.) and weighed, then soaked in distilled water, folded twice, and tied with thread. The culture chambers used were 2-quart fruit jars, which were prepared as follows: A piece of galvanized screen, 2¼ by 5½ inches, was bent down 1 inch from each end; this was placed in the bottom of the jar, and 100 cubic centimeters of distilled water were poured in. Three pieces of pulp, weighing 90 to 100 grams in all, were then placed in the jar on the screen, which supported them above the water. (See Pl. XIX, fig. 1.) A small extra piece of pulp, to be used for cultures and color comparisons at the end of the experiment, was placed in each jar, in close contact with the other samples in order to insure infection. The jars were then capped with a layer of cloth, a layer of cotton, then the top piece of the can lid, and finally with a layer of cloth over all. Two large rubber bands were used to fasten the cap in place. The jars were then sterilized by steaming in an autoclave at 100° C. for one hour on each of three successive days. After the last sterilization they were transferred immediately from the autoclave to the inoculating case, in which they were allowed to cool.

Sets of three jars each were inoculated with a pure culture of a fungus that had been isolated from pulp, pulp-wood, boards from pulp sheds, or river water. The following two methods of inoculation were used:

1. In the case of molds, a sporulating culture on a malt agar slant was used as the source of the inoculum. Five cubic centimeters of sterilized distilled water were poured into the culture tube, which was thoroughly shaken until a heavy spore suspension was obtained. Then three test tubes containing sterile water were opened and a third of the spore suspension was poured into each. The three spore suspensions resulting were then used to inoculate the pulp samples. One side of the jar cover was carefully lifted and the spore suspension poured over the tops of the pieces of pulp in the jar. Care was exerted to have the inoculation of the pieces of pulp as nearly uniform as possible, so as to establish a check.

2. The cultures inoculated with wood destroyers were treated as follows: Petri-dish cultures of the fungus in question were made on malt agar a week in advance, after which time they were cut into pieces about 8 millimeters square, and one square was placed on the top of each of the three pieces of pulp in the jar. The jars, as inoculated, were removed from the culture case. New rubber bands were substituted for the old ones, and white papers, to keep the dust from the caps, were placed over the tops and held in place by heavy rubber bands.

All the jars were then stored in an inside basement room in which the temperature was fairly constant (average 21° C.). The three jars of each set were opened at the end of 6, 9, and 12 months, respectively. At the end of the test the moisture content of the samples was determined, and the loss, based on oven-dry (100 to 105° C.) weight, was obtained for each culture. As each jar was opened the small extra piece of pulp was transferred to a sterile Petri dish and small pieces of it were then planted upon malt agar plates. The object of this procedure was to determine whether or not the fungus had remained viable throughout the experiment and whether the culture had remained pure. Results in these respects were positive except in the cases specially noted in the tables.

DATA AND DISCUSSION

Table 14 gives the results obtained with 29 cultures of molds, representing at least 26 distinct species. The loss in weight was small in all the mold-inoculated pulps. *Trichoderma* sp. (6520–2) caused the greatest loss in 12 months, 3.2 per cent. Four samples became some shade of pink, and nine became gray. Only three samples, which were gray, were dark enough to have spoiled the quality of paper made from them. The remaining 16 samples were recorded as "normal," which means that (1) the pulp itself retained its usual color; (2) the fungus did not make the pulp brittle, or, in so far as could be determined macroscopically, otherwise change its physical properties; and (3) the colored spores of the fungus, produced on the surface of the pulp, were in sufficiently small numbers and of such kind that they would ordinarily be washed off in the beater without causing any damage to the manufactured paper.

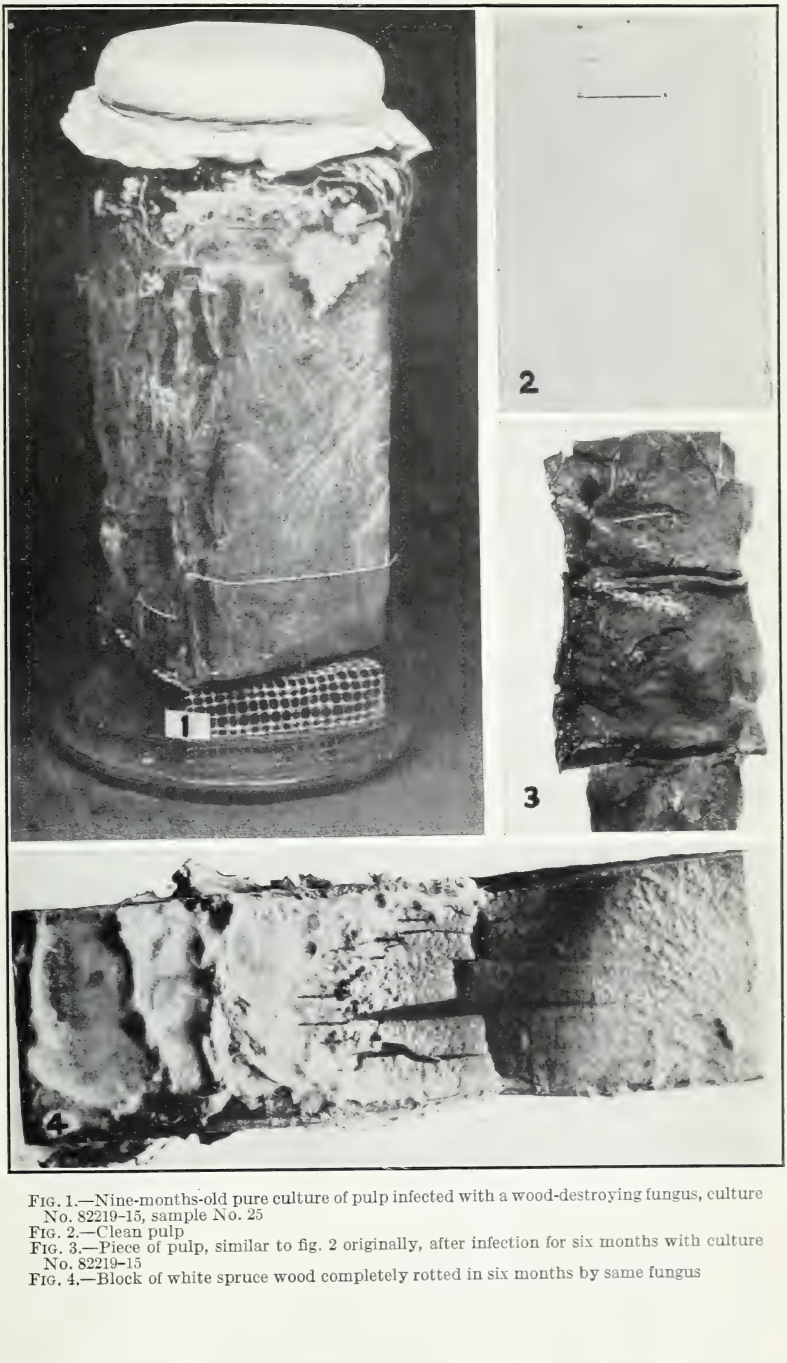
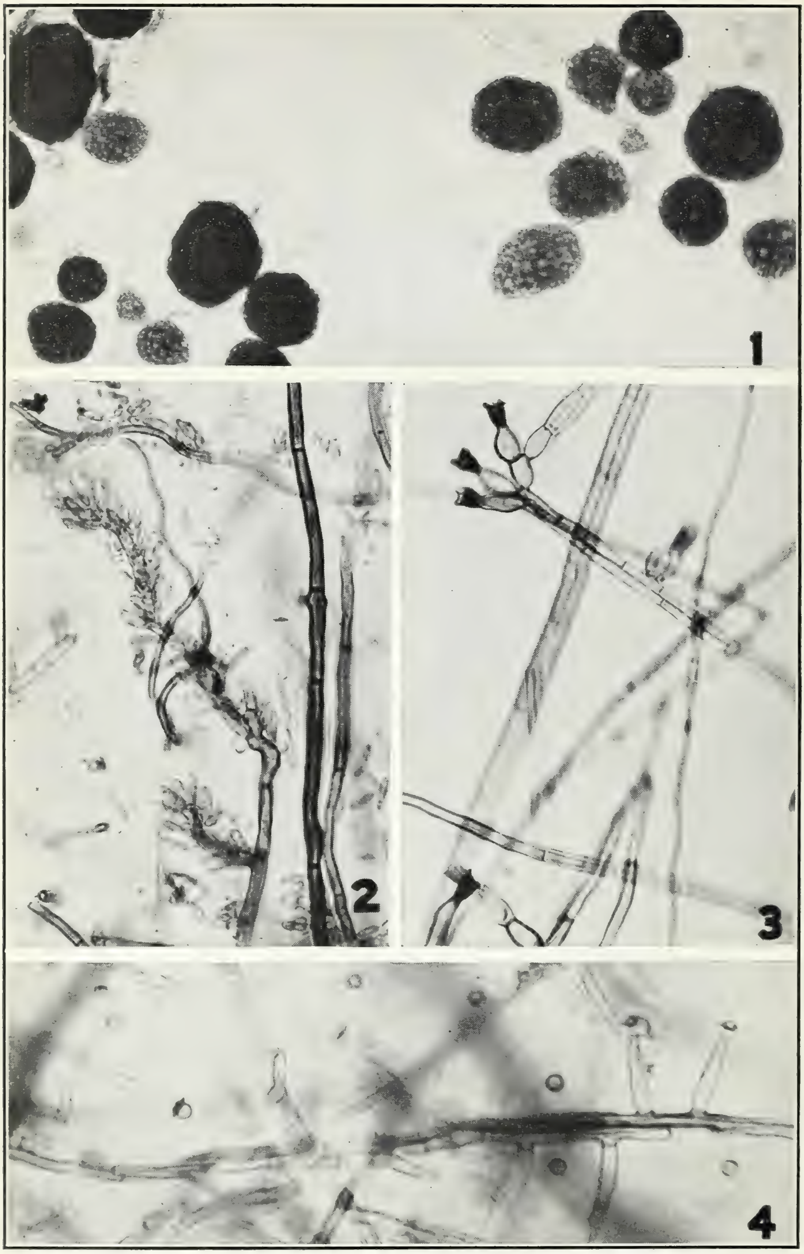


FIG. 1.—Nine-months-old pure culture of pulp infected with a wood-destroying fungus, culture No. 82219-15, sample No. 25
FIG. 2.—Clean pulp
FIG. 3.—Piece of pulp, similar to fig. 2 originally, after infection for six months with culture No. 82219-15
FIG. 4.—Block of white spruce wood completely rotted in six months by same fungus



REPRESENTATIVE MOLDS ISOLATED FROM GROUND-WOOD PULP

FIG. 1.—Bulbils of *Papulospora nigra* (× 150)
FIG. 2.—Conidiophores, spores, and mycelium of an unidentified species of Dematiaceae, culture No. 3818–1 (× 750)
FIG. 3.—Conidiophores and mycelium of an unidentified species of Dematiaceae, culture No. 10918–7 (× 750)
FIG. 4.—Conidiophores, spores, and mycelium of an unidentified species of Dematiaceae, culture No. 92219–2 (× 750)

Although at the outset care was taken to bring the pulp in the tests to a uniform condition of moisture the tables show that at the end the individual samples varied considerably, ranging from 53.6 to 73.3 per cent in moisture content. The average was 65 per cent, as compared with the approximately 70 per cent which pulp normally has when taken from the wet machines.

Table 15 gives the results obtained with 13 species of hymenomycetes—12 isolated from ground wood, and one (6920–2) from sulphite pulp. It will be noted that the figures recorded in Table 15 show results quite different from those in Table 14. Seven organisms caused sufficient color changes in the pulp to have appreciably discolored any paper manufactured from it. Five fungi made the infected pulp more or less brittle, and three caused it to become friable to the point of entire worthlessness. The most destructive of these organisms are those which are found most frequently on ground-wood.

The moisture content of the pulp samples at the end of these tests was somewhat higher, averaging 68.7 per cent, than in the tests made with the molds, although efforts were made to start all exactly alike. The condition may be accounted for in some cases by the fungus growing down into the water in the bottom of the jar, whence it conducted moisture to the pulp. All but two of the cultures remained viable until the end of 12 months. The two that died are not classed as vigorous wood destroyers.

TABLE 14.—*Deterioration of ground wood caused by 29 cultures of molds isolated from pulp and water*

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after— 6 months	9 months	12 months	Physical condition of pulp
196				0.5			
197	Uninoculated				(1)		Normal.
198			67.3			0.6	
88			69.0	1.0			
89	82219–11	*Mucor* sp	61.1		1.0		Do.
90			63.8			.8	
181			66.6	.8			
182	62020–1	*Oidium* sp	65.1		.8		Do.
183			64.3			1.4	
65				.3			
64	32019–1	*Trichoderma* sp	64.1		.3		Do.
66			57.6			1.0	
85			66.8	.5			
86	82219–10	do	61.0		1.0		Do.
87			62.0			1.2	
190			66.4	1.8			
192	6520–2 [2]	do	63.6		1.6		Do.
191			72.6			3.2	
112			72.7	1.2			
113	82219–6	*Fusarium* sp	68.4		1.1		Very slight pink.
114			58.1			1.1	
187			64.7	1.6			
188	6520–1 [2]	*Aspergillus fumigatus*	71.2		1.4		Normal.
189			73.3			3.0	
16				.4			
17	81318–2	*Penicillium* sp	68.9		1.0		Do.
18			59.0			.6	
19				1.8			
20	10918–9	do	67.8		1.5		Do.
33			60.5			1.5	
37				.9			
38	10918–3	do	67.8		1.8		Do.
39			63.4			2.0	

[1] Contaminated with *Penicillium* sp

[2] Isolated from water.

TABLE 14.—*Deterioration of ground wood caused by 29 cultures of molds isolated from pulp and water*—Continued

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after— 6 months	9 months	12 months	Physical condition of pulp
52			-------	0.8	-------	-------	
53	10918–11	*Penicillium purpurogenum.*	66.1	-------	1.6	-------	Pinkish.
54			66.8	-------	-------	1.6	
91			69.2	.5	-------	-------	
92	82219–12	*Penicillium* sp	63.6	-------	1.8	-------	Normal.
93			60.8	-------	-------	1.0	
184			64.9	2.1	-------	-------	
185	112217	*Penicillium pinophilum*	70.7	-------	1.9	-------	Pinkish, red in spots.
186			65.5	-------	-------	2.8	
193			65.1	2.0	-------	-------	
194	6520–3 [2]	*Penicillium* sp	67.5	-------	1.9	-------	Slightly pinkish.
195			73.0	-------	-------	2.5	
43			-------	1.2	-------	-------	
44	10918–6	*Citromyces* sp	66.4	-------	1.8	-------	Normal.
45			59.6	-------	-------	1.7	
55			-------	.5	-------	-------	
56	10918–12	*Citromyces* sp	67.9	-------	2.0	-------	Pinkish cinnamon.
57			63.5	-------	-------	1.6	
34			-------	.6	-------	-------	
35	10918–1	*Gliocladium* sp	62.1	-------	1.5	-------	Normal.
36			60.2	-------	-------	1.5	
48			-------	1.1	-------	-------	
46	10918–5	*Spicaria* sp	67.1	-------	1.4	-------	Do.
47			63.7	-------	-------	1.0	
10			-------	1.0	-------	-------	
11	32019–7	*Papulospora nigra*	65.4	-------	1.7	-------	Do.
12			63.4	-------	-------	1.7	
67			-------	1.0	-------	-------	
68	32019–2	*Alternaria* sp	61.9	-------	2.0	-------	Light gray.
69			58.7	-------	-------	1.7	
40			-------	.9	-------	-------	
41	10918–4	*Trichoderma* sp	65.3	-------	1.5	-------	Normal.
42			61.5	-------	-------	1.2	
9			-------	.6	-------	-------	
7	3818–1	Unidentified	69.8	-------	1.3	-------	Light gray.
8			59.4	-------	-------	1.1	
13			-------	1.0	-------	-------	
14	81318–1	do	62.8	-------	1.8	-------	Do.
15			63.9	-------	-------	1.8	
73			-------	.4	-------	-------	
74	82219–2	do	62.1	-------	1.9	-------	Light mouse gray.
75			59.9	-------	-------	1.4	
79			67.3	.5	-------	-------	
80	82219–5	do	63.3	-------	1.1	-------	Light gray.
81			58.3	-------	-------	1.2	
82			62.4	1.1	-------	-------	
83	82219–9	do	69.0	-------	1.9	-------	Do.
84			53.6	-------	-------	1.9	
94			66.1	1.2	-------	-------	
95	82219–18	do	69.0	-------	1.7	-------	Mouse gray.
96			67.5	-------	-------	2.4	
103			71.5	1.2	-------	-------	
104	10918–7	do	64.6	-------	1.5	-------	Deep neutral gray.
105			66.0	-------	-------	1.4	
116			73.2	1.6	-------	-------	
115	82219–23	do	59.3	-------	1.9	-------	Do.
117			68.5	-------	-------	1.4	
	Average		65.0	1.0	1.5	1.6	

[2] Isolated from water.

TABLE 15.—*Deterioration of ground wood caused by 13 hymenomycetes which were isolated from wood pulp*

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after— 6 months	9 months	12 months	Physical condition of pulp
196				0.5			
197	Uninoculated.				[1]		Normal.
198			67.3			0.6	
32				1.9			
30	102019–1	*Paxillus panuoides.*	65.3		2.8		Pinkish buff to russet; slightly brittle.
31			64.4			3.6	
5				4.2			
4	82219–4	Unidentified	74.2		5.6		Ochraceous buff or tawny, mottled with white; slightly brittle.
6			67.0			7.7	
21				2.2			
22	82219–13	do	69.8		[1]		Normal.
23			66.5			3.4	
26				18.1			
25	82219–15	do	73.4		21.1		Clay color to clove brown; friable.
24			76.1			26.4	
27	102019–1a			1.5			
28		do	69.1		2.3		Normal.
29			64.4			2.3	
49				1.0			
50	10918–10	do	68.7		1.8		Do.
51			56.3			3.6	
100			75.0	27.1			
101	4620–2	do			[2]		Cinnamon-buff to chaetura black; very friable.
102			79.8			49.5	
106			72.9	22.2			
107	4620–1	do	75.2		33.1		Do.
108			77.8			38.6	
127			73.2	11.6			
128	61020–1	do	72.4		18.7		Cinnamon-buff; very brittle.
129			72.3			18.9	
133			70.1	2.1			
134	61520–1	do	68.1		3.1		Normal, except maize yellow; chlamydospores on surface.
135			66.4			[3] 2.1	
163			66.7	2.3			
164	6920–2	do	64.0		2.4		Normal.
165			62.8			[3] 2.3	
166			68.8	4.1			
167	6320–1	do	67.7		5.2		Normal color; somewhat brittle
168			60.6			6.8	
172			67.3	3.3			
173	6920–1	do	62.2		5.1		Ochraceous buff or tawny, mottled white; slightly brittle.
174			60.6			7.9	
	Average		68.7	8.8	10.6	15.3	

[1] Contaminated.
[2] This culture was lost.
[3] Transplants did not grow. Results of this set not included in averages.

The loss in weight in 6 months varied from 1 to 27.1 per cent. The average loss in 6 months was 8.8 per cent. In 9 months from 1.8 to 33.1 per cent was lost, the average being 10.6 per cent. In 12 months from 2.3 to 49.5 per cent loss occurred, the average being 15.3 per cent. (See fig. 2.)

Table 16 records the results obtained with 11 hymenomycetes isolated from wood and one isolated from water. All except one of these fungi discolor pulp to such an extent as to damage the paper made from it. Eight species made the pulp more or less brittle, and one made it so friable as to be absolutely worthless. The moisture content of the samples varied from 55.8 to 72.5 per cent, the average being 64.7 per cent. Four of the fungi died before the end of 12 months, these being the least virulent of this group of wood destroyers.

The loss in weight in 6 months varied from 1.8 to 21.5 per cent, the average loss being 10.5 per cent. In 9 months from 2.2 to 30.3

per cent was lost. The average loss was 14.4 per cent. In 12 months from 5.5 to 40.2 per cent was lost; average, 18 per cent. The four sets of tests in which the fungi died are not counted in the results.

The loss in the check cultures shown in all three tables is to be attributed to the changes brought about by sterilization and drying and to some slight loss due to handling; hence an experimental error of from ± 0.4 to ± 0.6 per cent should be allowed in all cases.

It will be observed that in some instances the loss in weight in 12 months was less than in one of the shorter periods. The following

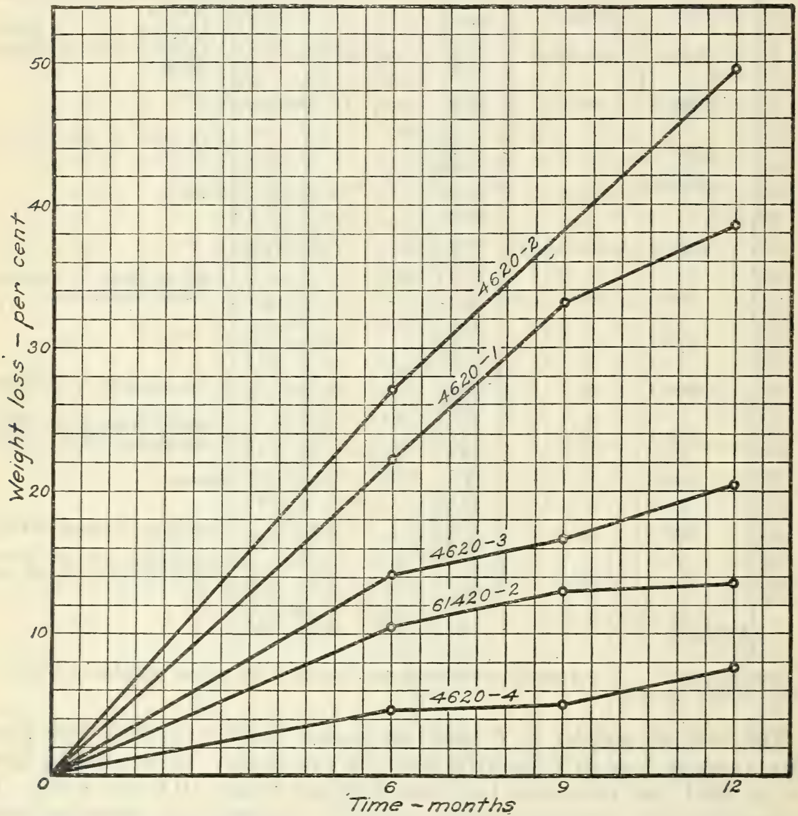


FIG. 2.—Graphs showing loss in weight of ground-wood pulp after infection in pure culture by various wood-destroying fungi

facts are offered in explanation of this apparent anomaly: Some, at least, of the tests indicate a decrease in the vitality of the organisms. Moreover, the weight of the fungous mycelium has not been taken into account; this will vary considerably, according to the nature of the fungus in question, and may amount to as much as several grams. Buromsky (*8*) reports a growth of 2.4 grams for *Aspergillus niger* when grown in favorable culture solutions, whereas some of the species used in the tests, especially among the hymenomycetes, produce a much more luxuriant growth of mycelium than does *Aspergillus niger.*

TABLE 16.—*Deterioration of ground wood caused by 11 hymenomycetes isolated from wood and one from water*

Sample No.	Culture No.	Organism	Per cent moisture	Per cent loss in weight after—			Physical condition of pulp
				6 mos.	9 mos.	12 mos.	
196				0.5			
197	Uninoculated				(1)		Normal.
198			67.3			0.6	
157			67.6	21.5			
158	61420-1	*Lentinus lepideus*	71.7		30.3		Cinnamon to sayal brown; very friable.
159			70.3			40.2	
130			70.3	10.3			
131	61420-2	*Fomes roseus*	67.2		12.9		Cinnamon-buff to clay color; somewhat brittle.
132			68.1			13.5	
139			66.4	1.8			
140	62520-1	*Stereum sanguinolentum*	62.8		2.2		Cinnamon.
141			60.8			[2] 2.8	
142			62.0	2.2			
143	62520-2	*Corticium galactinum*	60.4		3.3		Cinnamon-buff.
144			62.5			[2] 2.8	
148			70.0	13.5			
149	8620-1	*Peniophora tabacina*	70.6		19.5		Cinnamon-buff; very brittle.
151			57.1			22.4	
136			62.8	8.7			
137	61420-3	Unidentified	58.9		13.9		Pinkish buff; very brittle.
138			60.8			18.1	
145			63.7	3.2			
146	62220-1 [3]	do	63.1		4.2		Cinnamon-buff to clay color; slightly brittle.
147			55.8			5.5	
152			67.0	7.9			
150	61420-7	do	67.8		12.8		Cinnamon-buff; very brittle.
153			58.9			16.1	
154			67.6	2.0			
155	61420-5	do	65.1		2.4		Normal.
156			61.8			[2] 2.3	
160			65.6	2.8			
161	61420-4	do	63.9		2.6		Cinnamon-buff; slightly brittle.
162			64.6			[2] 2.4	
175			66.6	4.7			
176	4620-4	do	60.9		5.0		Clay color; slightly brittle.
177			62.1			7.6	
178			69.3	14.1			
179	4620-3	do	63.4		16.6		Cinnamon-buff; very brittle.
180			72.5			20.4	
	Average		64.7	10.5	14.4	18.0	

[1] Contaminated.
[2] Transplants did not grow. Results of this set not included in averages.
[3] Isolated from river water.

Trichoderma sp. (6520–2), *Aspergillus fumigatus*, *Penicillium* sp. (6520–3), and *P. pinophilum* dissolve cellulose when planted upon cellulose agar (McBeth and Scale's formula) and kept at 28° C. In the pulp, at about 21° C., however, they produce a loss in weight of only 1.4 to 3.2 per cent, which is far below what might be expected of cellulose-dissolving organisms. Under commercial methods of storage *Trichoderma* sp. (82219–10) turns pulp bright yellow; *Penicillium pinophilum* and *P. purpurogenum* and other species of Penicillium produce red discolorations which vary from light pink to purple-red; *Spicaria* sp., *Alternaria* sp., and two unidentified cultures (82219–2, 82219–18) cause brown spots which would appreciably lower the quality of paper made from pulp infected by them; and eight of the unidentified molds (3818–1, 81318–1, 82219–5, 82219–9, 10918–7, 82219–23, and 82219–21) produce gray pulp.

Since the more pronounced discolorations common to the above fungi did not occur in the jar tests, one can only conclude that some factor was unfavorable to their best development in the series of experiments reported. As in the case of molds, some of the hymenomycetes have been observed to cause much more damage under normal conditions of storage than they did in pure culture tests.

Among the factors contributing to this reduced activity of the fungi in certain of the artificial cultures, both temperature and moisture doubtless play an important part. No one temperature would be the one most favorable for the maximum growth of all the 54 species tested. The temperature of 21° C., at which the cultures were stored, would be too low for the most vigorous growth of many of them. Laboratory temperature (approximately 22 to 28° C.) appeared to be better. (See Pl. XIX, figs. 2 and 3.) The moisture requirements may also vary greatly for the different fungi. (See

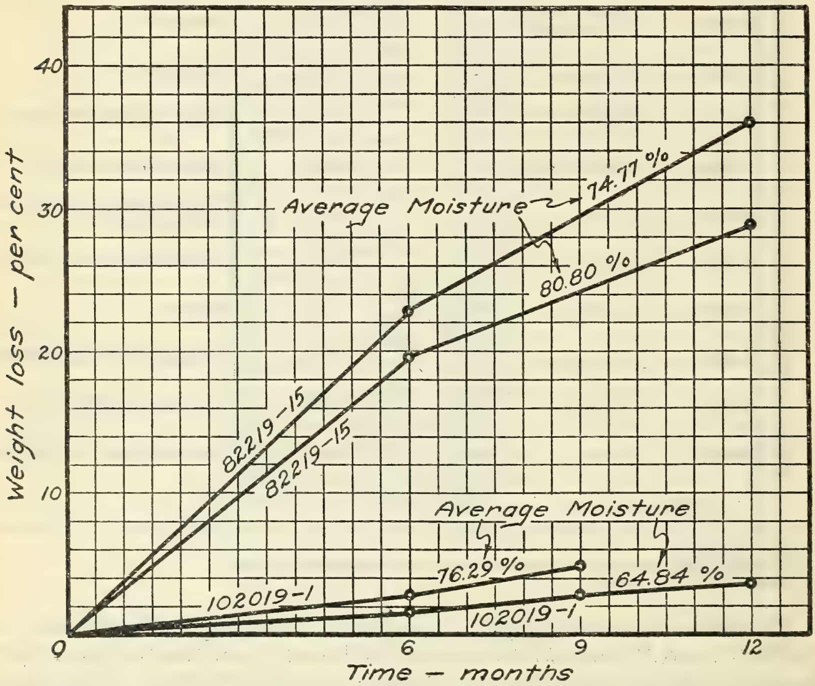


FIG. 3.—Graphs showing loss in weight of ground-wood pulp due to pure cultures of two wood-destroying fungi under two different moisture conditions

fig. 3.) In some of the jars the pulp evidently became either too dry or too wet for the maximum growth of the fungi. (Refer to Table 14 for pronounced variations in moisture content.)

CHEMICAL PROPERTIES

It has been demonstrated that the growth of the organisms of decay in wood pulp is accompanied in most cases by a loss in weight of the pulp. From data available in the technical literature (*22*) it is evident that under the action of these organisms the complex wood substance is broken down into simpler compounds, some of which are water-soluble and some of which pass off as gases. With this in mind, a study was made to determine the changes in the chemical properties of some of the ground-wood pulps the physical properties of which have just been discussed. (See Tables 14, 15, and 16.) The changes that accompany the action of molds and of wood-destroying fungi appear to be different, in degree, at least, if not in kind.

EFFECT OF MOLDS

In Table 17 are presented the results of the chemical analyses of ground-wood pulps inoculated with 26 molds in pure culture and subjected to storage for periods of 6, 9, and 12 months. The loss in weight is also shown. The data in all cases are calculated on the basis of the original dry weights of the samples taken.

TABLE 17.—*Chemical analyses of ground-wood pulp deteriorated by pure cultures of molds*

Sample No.	Incubation period	Organism or culture No.	Original loss	Cold water soluble	Hot water soluble	Sodium hydroxide soluble	Lignin	Cellulose
	Months		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sound pulp			0.0	0.0	1.0	10.1	29.7	60.0
9	6		.6	.2	1.5	11.7	28.1	59.0
7	9	3818-1	1.2	.8	2.1	12.9	28.2	58.4
8	12		1.0	1.8	4.4	14.4	29.0	58.0
43	6	*Citromyces* sp	1.1	.0	1.2	14.5	28.5	57.8
45	12		1.7	1.0	3.4	14.4	29.0	57.7
52	6		0.7	1.8	2.8	14.8	29.0	60.0
53	9	*Penicillium purpurogenum*	1.6	1.0	1.9	13.7	28.5	57.4
54	12		1.5	.9	3.4	15.5	29.1	58.8
55	6		.4	1.1	2.5	14.3	29.1	57.6
56	9	*Citromyces* sp	1.9	1.4	2.7	14.3	28.5	57.1
57	12		1.6	1.1	4.4	13.0	29.1	57.7
73	6	82219-2	.3	.6	1.3	14.2	29.2	58.5
75	12		1.4	.1	3.2	13.0	29.3	56.8
82	6		1.2	.8	1.8	12.7	28.5	57.3
83	9	82219-9	1.8	.0	1.4	12.4	27.8	58.3
84	12		1.9	.0	3.0	12.5	29.5	56.6
116	6		1.5	.8	.0	10.9	29.0	58.2
115	10	82219-6	1.9	1.5	2.1	13.0	29.1	56.8
117	12		1.3	1.5	3.1	13.9	30.1	57.5
118	6	82219-21	1.1	1.2	.3	10.6	29.0	59.2
120	12		1.0	2.0	3.2	14.6	30.1	57.2
94	6	82219-18	1.1	.9	1.8	11.4	29.0	57.9
95	9		1.6	.5	1.8	13.2	29.1	55.4
10	6	*Papulospora nigra*	1.0	.7	1.7	15.8	28.3	56.3
11	9		1.6	.7	4.1	14.9	29.0	50.0
19	6	*Penicillium sp*	1.7	.8	1.2	12.4	28.1	57.7
20	9		1.4	.8	2.8	12.0	28.8	59.0
34	6	*Gliocladium* sp	.6	.2	2.2	14.5	29.1	56.7
35	9		1.4	1.3	3.3	14.3	29.3	58.6
48	6	*Spicaria* sp	1.0	.0	.3	12.7	28.4	59.7
46	9		1.4	.8	2.9	13.5	29.7	56.0
91	6	*Penicillium* sp	.4	1.5	2.7	13.3	28.7	56.6
92	9		1.8	1.5	3.3	16.5	28.5	56.1
103	6	10918-7	1.2	1.5	1.1	11.1	28.7	57.0
104	10		1.4	3.0	3.8	12.7	29.0	57.4
13	6	81318-1	.9	.2	2.0	12.9	28.1	57.3
16	6	*Penicillium* sp	.4	.5	1.4	13.5	28.0	58.0
37	6		.9	.5	2.1	15.5	29.1	57.1
40	6	10918-4	.8	.7	1.8	15.1	29.2	57.5
65	6	*Trichoderma* sp	.3	.8	1.8	13.3	28.9	58.0
67	6	*Alternaria* sp	.9	.6	1.6	13.6	28.8	57.5
70	6	82219-1	.1	1.1	1.8	13.3	28.9	58.5
85	6	*Trichoderma* sp	.4	1.6	2.1	14.0	28.8	57.6
88	6	*Mucor* sp	.9	1.5	2.7	13.5	28.4	56.7
112	6	82219-6	1.2	1.4	1.1	11.4	29.0	58.6
122	6	*Mucor* sp	1.6	.9	.0	10.4	29.4	58.5

A comparison of these data with the data for sound pulp shown in the same table indicates that only small changes were produced. The loss in weight in no case exceeded 2 per cent, and the increase in solubility in cold water, hot water, and sodium hydroxide did not exceed 3 per cent, 3.5 per cent, and 6.5 per cent, respectively. In only one case was the loss in cellulose greater than 4 per cent. The slow rate of deterioration is evident from the typical set of curves, Figure 4. The 10 per cent loss in the case of *Papulospora nigra* is not excessive nor indicative of far-reaching decomposition; it approaches

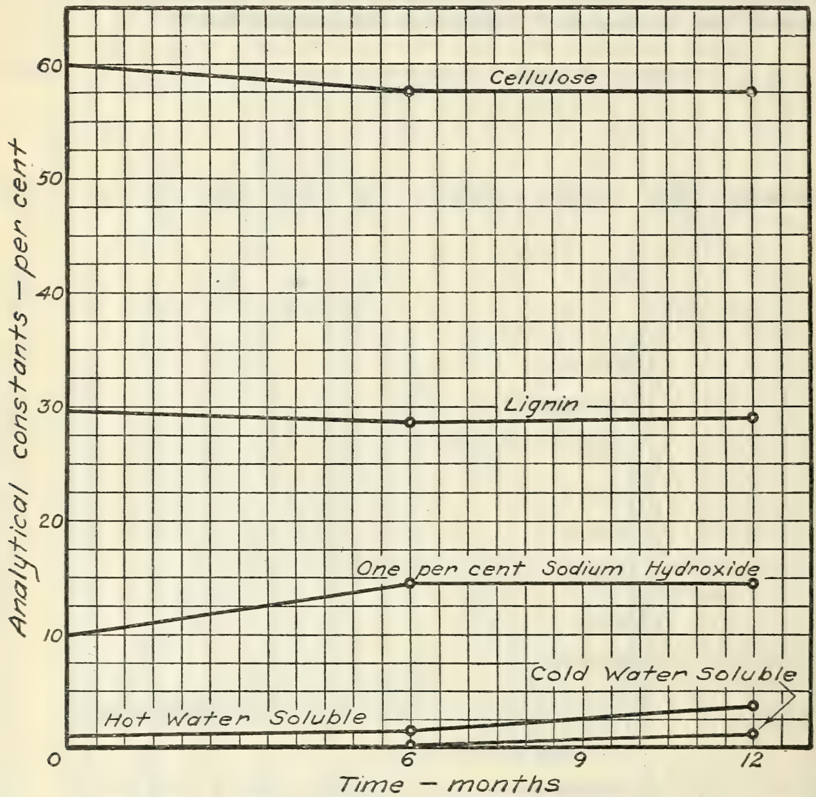


FIG. 4.—Graphs showing analytical constants of ground-wood pulp infected with a mold culture, No. 10918-6

in value, however, some of the losses due to some wood destroyers, which is to be expected since *Papulospora nigra* is closely related to the hymenomycetes.

EFFECT OF WOOD-DESTROYING FUNGI

That the action of wood-destroying fungi on the chemical components of ground-wood pulp is more vigorous then that of molds, will be seen from a study of Table 18 in which are set forth the chemical data for one sound ground-wood pulp, and ground-wood pulps inoculated with 21 of these fungi.

TABLE 18.—*Chemical analyses of ground-wood pulp deteriorated by pure cultures of hymenomycetes*

Sample No.	Incubation period	Organism or culture No.	Original loss	Cold water soluble	Hot water soluble	Sodium hydroxide soluble	Lignin	Cellulose
	Months		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sound pulp			0.0	0.0	1.0	10.1	29.7	60.0
26	6	82219-15	18.1	4.9	9.0	37.8	28.8	35.5
25	9		21.1	5.9	10.5	37.6	28.4	33.4
24	12		26.3	6.4	11.3	38.3	28.8	27.8
100	6	4620-2	27.1	8.0	13.0	40.0	27.7	26.8
102	12		49.4	7.3	11.0	33.4	26.6	10.8
106	6	4620-1	22.2	9.5	13.7	40.7	30.7	29.0
107	10		33.1	11.1	15.2	41.6	28.8	18.2
108	12		38.6	9.1	13.0	38.0	28.5	16.9
127	6	61020-1	11.5	3.9	7.2	30.9	29.1	40.6
128	9		18.9	6.1	8.9	32.5	29.5	36.9
130	6	*Fomes roseus*	10.3	2.8	5.7	29.6	30.6	44.2
131	9		12.9	3.2	5.1	29.2	30.7	44.1
148	6	*Peniophora tabacina*	13.5	4.8	8.9	34.9	27.7	40.4
149	9		19.4	4.9	7.9	37.2	32.0	35.1
178	6	4620-3	14.1	6.0	9.8	33.0	29.3	38.0
179	9		16.5	6.5	10.2	36.3	29.0	37.3
152	6	61420-7	7.9	4.2	7.0	25.5	29.0	48.8
150	9		12.8	5.3	8.5	40.2	34.6	38.0
157	6	*Lentinus lepideus*	21.5	7.5	11.8	41.0	28.8	32.0
158	9		30.3	9.6	15.7	40.5	28.6	24.2
5	6	82219-4	4.1	2.3	5.4	21.0	26.8	56.0
4	9		5.6	2.1	6.0	19.7	27.3	54.7
6	12		7.6	3.6	7.5	21.6	26.6	53.4
27	6	102019-1a	1.4	2.3	4.6	14.1	29.4	56.7
28	9		2.3	1.9	3.5	13.8	29.1	58.0
32	6	*Paxillus panuoides*	1.9	0.0	1.6	13.6	28.7	55.6
30	9		2.8	0.6	5.0	14.4	28.4	55.8
31	12		3.5	1.3	4.5	17.8	27.7	55.9
49	6	10918-10	1.0	0.0	0.5	13.0	28.7	57.6
50	9		1.7	0.1	2.4	12.0	29.6	57.0
133	6	61520-1	2.0	1.5	3.2	13.9	29.4	57.4
136	6	61420-3	8.6	5.0	7.8	30.6	29.3	45.1
137	9		13.9	5.9	10.0	37.2	29.2	38.3
142	6	*Corticium galactinum*	2.1	1.7	2.9	15.8	28.4	57.2
145	6	62220-1	3.1	1.1	2.3	14.5	28.4	57.7
146	9		4.1	2.2	3.9	19.5	32.0	56.0
160	6	61420-4	2.7	1.7	3.0	17.1	28.9	55.8
172	6	6920-1	3.3	2.3	3.6	15.8	28.8	56.4
173	9		5.1	2.7	5.5	22.0	27.2	53.8
175	6	4620-4	4.7	3.2	5.7	20.7	27.4	54.8
176	9		5.0	2.7	4.7	20.8	26.9	54.6
181	6	62020-1	0.8	1.9	2.1	14.2	29.1	50.5

The large losses in weight, which with one fungus reached 27.1 per cent in six months and 49.5 per cent in 12 months, were reflected in the chemical data. The solubility in cold and hot water and in sodium hydroxide in practically all cases increased very substantially, and reached maxima of 11.1 per cent, 14.7 per cent, and 40 per cent, respectively. The decreases in cellulose content were also very marked. The reduction in one case was 10.9 per cent.

In striking contrast with the other chemical data is the fact that the lignin content remained practically constant and independent of decay. Its variations from the value of sound pulp were not much greater than the experimental error. The action of the fungi investigated was, therefore, apparently selective in that it did not involve to any appreciable extent of decomposition of lignin. Unfortunately it was the cellulose, which from the paper-making standpoint is the most important part of the wood, which suffered the greatest deterioration.

Fomes roseus, *Peniophora tabacina*, and cultures 82219–15, 4620–2, 4620–1, 61020–1, and 4620–3, acted rapidly during the first six months of storage, as is indicated by the great changes recorded. After six months the rate of change decreased very noticeably. This is evident from the curves shown in Figure 5, which are typical of these cultures. The decrease in rate of deterioration may be accounted for in one or all of the following three ways:

1. There may be a decrease in the vitality of the organism, due perhaps to autointoxication.

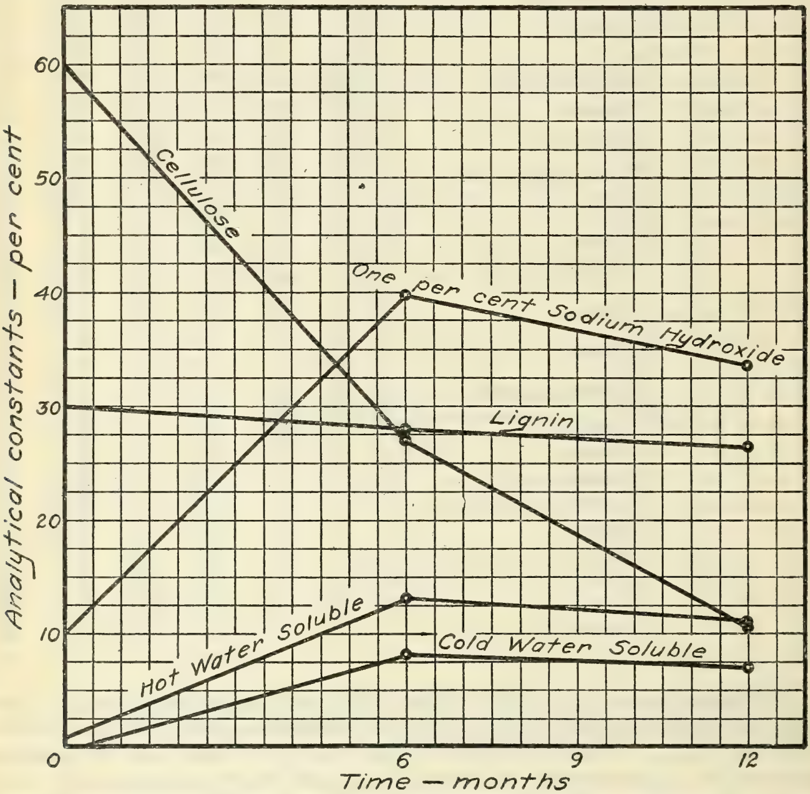


Fig. 5.—Graphs showing analytical constants of ground-wood pulp infected with a hymenomcete culture, N. 4620–2

2. The cellulose which remains after a certain period may not be available to the fungus. Assuming that the fungus uses the more accessible cellulose, leaving the lignin, the remaining cellulose in the ligno-cellulose complex may be more or less encrusted with pure lignin and so protected, to a certain extent, against further breaking down.

3. The cellulose in the cell walls of the fungus, although somewhat different from ordinary cellulose, may cause a slight increase in the cellulose determination.

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